JUNE 1968

IONOSPHERIC ELECTRON CONTENT– SYNCHRONOUS ORBIT BEACON EXPERIMENT DEFINITION

FINAL REPORT – CONTRACT NAS 8-21220

HUGHES

HUGHES AIRCRAFT COMPANY
SPACE SYSTEMS DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER/HUNTSVILLE, ALABAMA
CONTRACT NO. NAS 8-21220/HUGHES REF. NO. B4619

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CONTENTS

1. INTRODUCTION

This document is the final technical report for NASA Contract 8-21220 and is a follow-on effort to NASA Contract 8-18116. Both contracts are entitled "Ionospheric Electron Content Synchronous Orbit Beacon Experiment Definition." The work on both contracts has been accomplished by the Space Systems Division of Hughes Aircraft Company for the Scientific Flight Payloads Branch, George C. Marshall Space Flight Center.

The objective of the contracts is to provide two alternate design concepts for ionospheric beacon satellites that can be used for a synchronous Apollo Radio Beacon Experiment. The satellites would be deployed from a synchronous orbit Apollo Applications Program (AAP) spacecraft to measure the electron content of the exosphere and ionosphere. The first contract provided a design concept for a satellite that could be deployed and maintained in the Apollo spacecraft orbit (current indications are that this will be a 28.5 degree inclined synchronous orbit). For the purposes of the first report, this satellite was called the Ionospheric Beacon Satellite (IBS) and is described in Reference 1.

The second contract, described in this report, provides a design concept for a satellite that can change or remove inclination after deployment from an AAP vehicle in an inclined synchronous orbit. For the purposes of this report, it is called an Inclination Removel Ionospheric Beacon Satellite (IRIBS).

The scope of the work in Contract NAS 8-21220 defines the following two tasks:

1) "Design, fabricate and deliver a full scale mechanical integration model of the Synchronous Apollo Radio Beacon Experiment."
2) "Design a modification to the Synchronous Apollo Radio Beacon Experiment which would enable it to change the plane of its orbit from an initial 28 degrees inclination with respect to the equatorial plane to an inclination of less than five (5) degrees."

Both the IBS and the IRIBS must be capable of supplying Faraday rotation, dispersive doppler, and group path delay of the earth's ionosphere for measurement by ground-based stations. This requires a system which, in the absence of the ionosphere, would deliver to a ground-based recording station a linearly polarized 40.01 MHz signal whose electric vector would remain in a fixed direction, and a 360.090 MHz signal that would maintain its harmonic relation to the 40.010 MHz signal. Each signal must be capable of being amplitude modulated by a 20 kHz signal upon ground command.

The IBS and the IRIBS designs have been based on the Hughes-built HS-303 Early Bird synchronous communication satellite which has been operating successfully, without failure, since 6 April 1965. The satellite design will allow ground command to orient and position the satellite and command the ionospheric beacon on and off. A 3 year minimum lifetime, with stationkeeping, has been designed into the satellite. The design will accommodate other experiments, provided the allowable volume, weight, and balance do not exceed the stated maximums.

The principal difference between the two satellites is that the IRIBS retains the original Early Bird satellite apogee motor which is the 71 pound JPL Syncom motor. This motor can provide an inclination removel of 28.5 degrees. Therefore, the IRIBS deployed by an AAP vehicle in a 28.5 degree inclined synchronous orbit can use the Early Bird apogee motor to place the IRIBS in a synchronous equatorial orbit.

2. IBS MECHANICAL INTEGRATION MODEL

The synchronous Apollo radio beacon experiment mechanical integration model was delivered to the George C. Marshall Space Flight Center in January 1968. In accordance with NASA Contract NAS 8-21220, the IBS model was designed as specified in Reference 1. This section gives a brief description of the model. Figure 2-1 is a photograph of the model at delivery, Figure 2-2 shows a cutaway view of the model, and Figure 2-3 is a general arrangement drawing of the satellite.

The IBS model can be integrated into a mechanical integration model of the synchronous Apollo spacecraft. Provisions have been made for the later installation of prototype electronic equipment to determine the r-f characteristics of the beacon antenna system and the interface of the beacon transmitter electronics with the satellite. The Synchronous Apollo Radio Beacon Experiment mechanical integration model conforms to the following specifications:

1) Outside envelope — The dimensional tolerances are sufficiently close to permit adequate evaluation of spatial compatibility of the Synchronous Apollo Spacecraft and the Radio Beacon Experiment in both the launch and orbital configurations. To all outward appearances, the Radio Beacon Experiment looks like a flight model except that the solar cells are simulated.
2) Apollo/beacon interface — Since the exact configuration of the Synchronous Apollo Spacecraft is not defined at present, the interface hardware is not provided with the model. However, the portion of the interface which is an integral part of the satellite is included on the model, and an adapter is supplied to hard mount the model.
3) Structure — Since the mechanical integration model will not be used for testing structural integrity, a reasonable facsimile of parts has been substituted, dispensing with the usual quality control, inspection, and precision machining procedures.

4) Mechanical subsystem components — The subsystem components, such as the hydrogen peroxide reaction control system, jets, beacon support tube, forward thermal shield, and peroxide tanks, are nonfunctioning and are made of spinnings or machined aluminum.
5) Electronic subsystem components — The subsystem components are of wood or other simulations of correct size. Since the functional electronic components may be installed in place of the simulated electronic components at a later date, the structural and electrical interfaces can be made functional.
6) Weight and balance — The mass and center of gravity of the mechanical integration model are quite close to the computed values of the flight version of the satellite.
7) Environmental — The model can withstand the stresses of normal laboratory handling and Synchronous Apollo mockup installation.

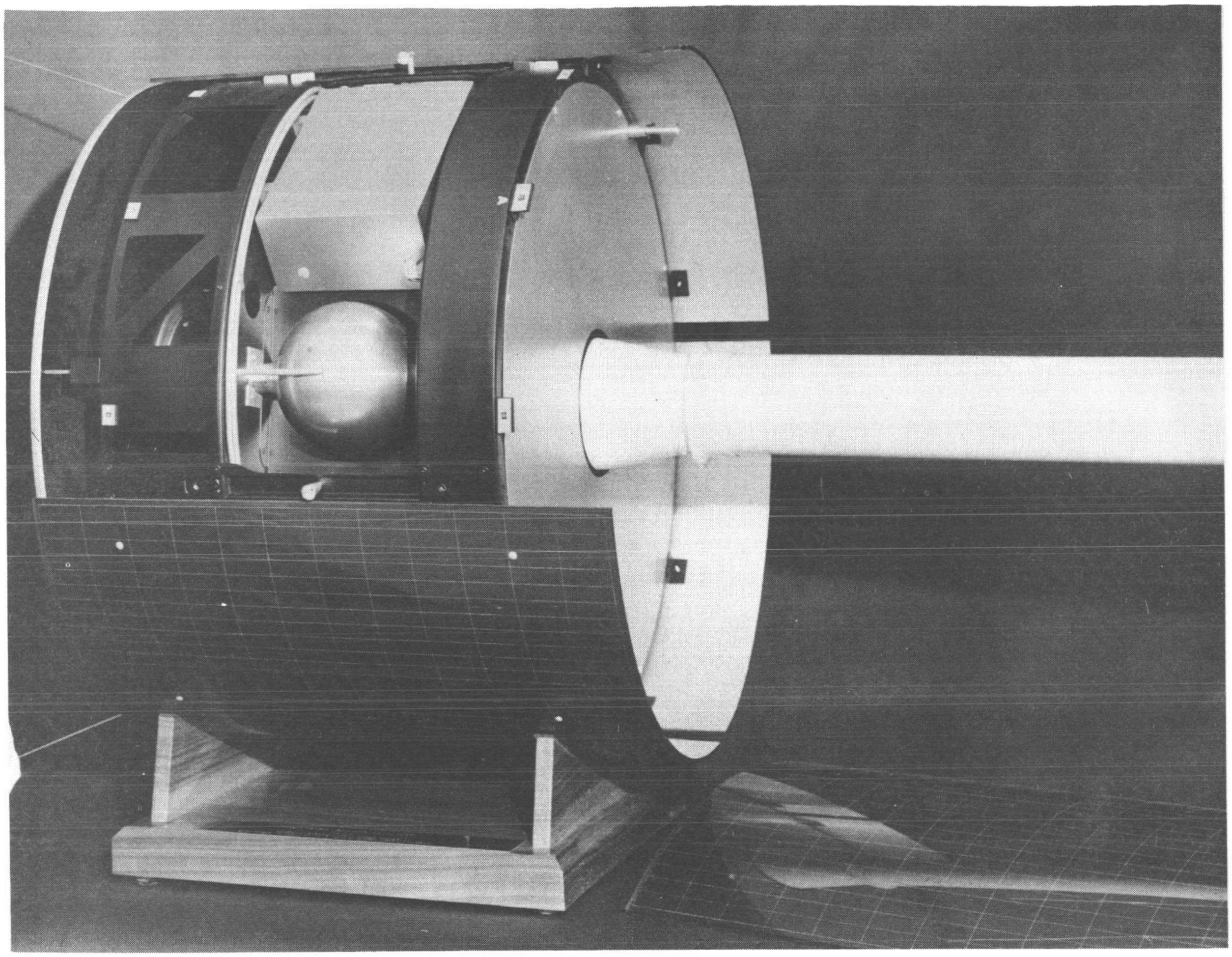

Figure 2-1. IBS Model With Solar Panel Removed
(Photo ES 1 68 20744)

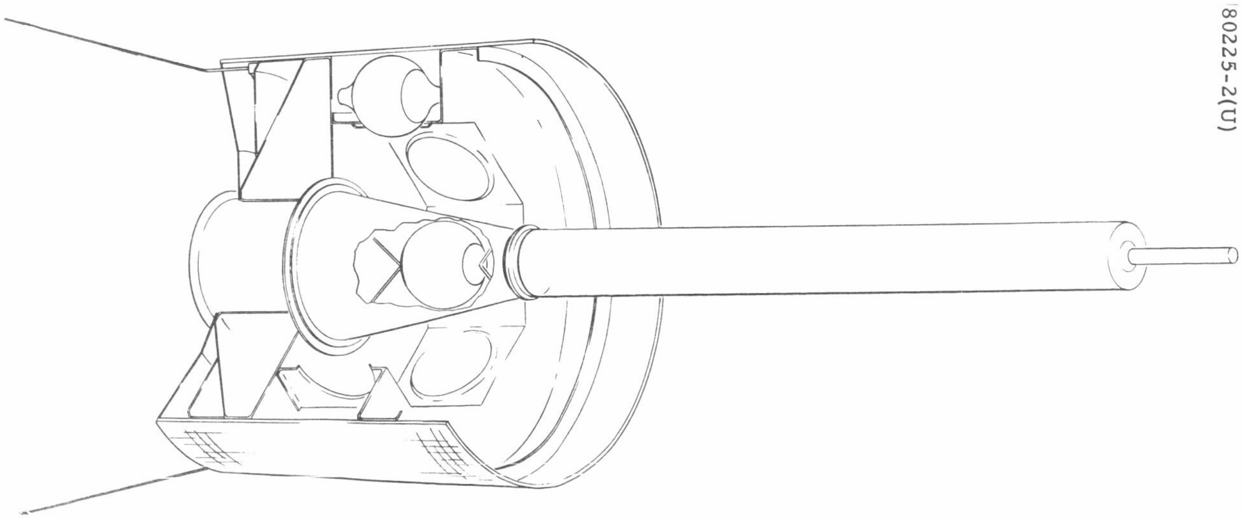

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Figure 2-2. IBS Model Cutaway View

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FOLDOUT FRAME 2

FOLDOUT FRAME 3

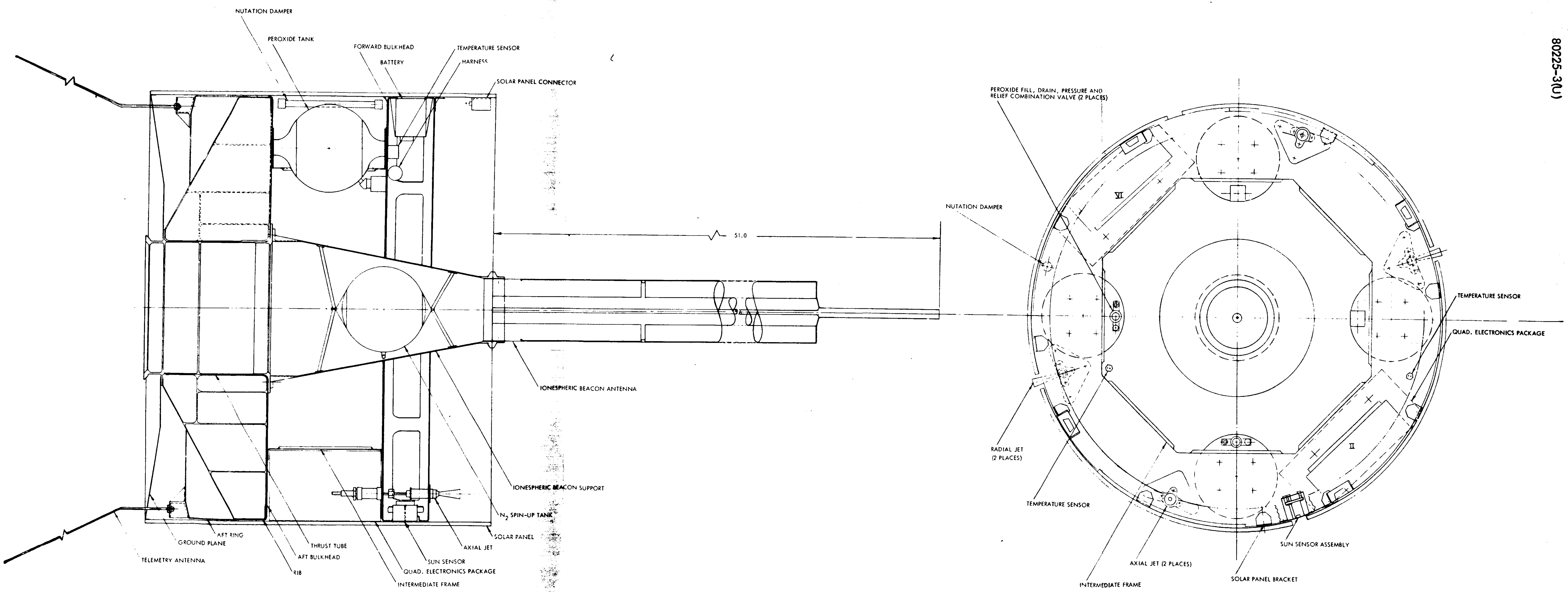


Figure 2-3. Ionospheric Beacon Satellite General Arrangement

3. INCLINATION REMOVAL IONOSPHERIC BEACON SATELLITE

The design of the IRIBS and IBS is based on the Hughes-built HS-303 Early Bird synchronous communication satellite which has been operating successfully, without failure, since 6 April 1965. The performance and operation of these satellites will be nearly identical after the desired synchronous orbit is achieved. The satellite design will allow ground command to orient and position the satellite and command the ionospheric beacon on and off. A 3 year minimum lifetime, with stationkeeping, has been designed into the satellite. The design will accommodate other experiments, provided the allowable volume, weight, and balance do not exceed the stated maximums.

Both satellites will be deployed from a manned Apollo vehicle into a 28.5 degree inclined synchronous orbit. The IBS will operate in the 28.5 degree orbit during its useful life; the IRIBS will be deployed in a like manner in a 28.5 degree orbit. However, the IRIBS can execute a 28.5 degree plane change, resulting in a stationary synchronous orbit on the equator.

IRIBS ORBIT CONSIDERATION

The IBS, proposed as a result of the Ionospheric Electron Content — Synchronous Orbit Beacon Experiment Definition (Contract NAS 8-18116), does not have a significant inclination removal capability. Current indications are that the IBS will be deployed from an AAP vehicle in a 28.5 degree inclined synchronous orbit. At best, the IBS hydrogen peroxide control system could reduce the inclination only by about 4 degrees. However, an apogee motor could remove 28.5 degrees of inclination, producing a stationary orbit. Such an apogee motor and its use are described in this subsection.

JPL Syncom Motor Performance

The IBS is basically an Early Bird satellite with the apogee motor replaced by the IBS ionospheric beacon antenna and a nitrogen cold gas spin-up tank. The simplest IBS inclination removal technique is to use the Early Bird apogee motor which has been integrated and proven on the Early Bird satellite and fits the general requirements for IRIBS inclination removal. The Early Bird apogee motor, also used for the second Syncom satellite, is the JPL Syncom motor. Its characteristics are listed in Table 3-1.

The flight motor would be delivered to Cape Kennedy apart from the IBS. Following satellite checkout and calibration, the motor is installed in the spaceframe in a spin balance facility. The motor is aligned so that its geometric axis coincides with that of the satellite. This eliminates all but insignificant imbalances in the satellite and assures that the motor will thrust through the spin axis.

The motor squib firing circuitry, shown in Figure 3-1, prevents accidental apogee motor firing, but at the same time assures that the motor will ignite when commanded to do so. Two parallel paths exist for firing the motor. These paths are separate inasmuch as parallel decoders, separation switches, and squibs are involved, but the squib shorting plug is consolidated into a single unit.

The squibs would be installed in the motor when it is installed into the satellite prior to mounting on the AAP vehicle. A JPL shorting plug would be installed directly into the squib harness and remain there to maintain the squibs in a safe configuration until its removal by the astronaut in orbit. Once the squib harness is mated to the spacecraft harness, the squib firing circuitry functions as follows:

1) A squib shorting plug, installed in a special receptable, shorts each squib in two places. It would be removed by the astronaut just prior to IRIBS deployment.
2) Separation switches would provide double safety by shorting the squibs until satellite separation from the AAP vehicle. Once separation has taken place, the firing circuit is primed for command firing.
3) The command to fire must be preceded by the closing of a safety-wired interlock switch on the command panel. As an

TABLE 3-1. IRIBS MOTOR CHARACTERISTICS
(JPL Syncom)

Parameter	Characteristic
Total weight	71.00 pounds (32.2 kg)
Inert weight	10.50 pounds (4.75 kg)
Propellant weight	60.50 pounds (27.4 kg)
Center of gravity	
Inert parts	8.5 inches aft of attach plane (21.6 cm)
Loaded assembly	6.0 inches aft of attach plane (15.25 cm)
Dynamic imbalance	
Inert parts before firing	Less than 1.0 oz-in^2 (183 gm-cm^2)
Inert parts after firing	Less than 5.0 oz-in^2 (915 gm-cm^2)
Loaded motor assembly	Less than 50 oz-in^2 (9150 gm-cm^2)
Thrust misalignment	Less than 0.002 in/in
Moment of inertia	
Loaded motor	
Roll	1308 lb-in^2 (3820 kg-cm^2)
Pitch (about center of gravity)	1648 lb-in^2 (4820 kg-cm^2)
Empty motor	
Roll	163 lb-in^2 (476 kg-cm^2)
Pitch (about center of gravity)	448 lb-in^2 (1311 kg-cm^2)
Performance, 80°F	
Maximum thrust	1120 pounds (508 kg)
Maximum pressure	250 psi (17.55 kg/cm^2)
Burning time	19.7 seconds
Total impulse	16,600 lb-sec (7530 kg-sec)
Ignition system pressure	360 psia (25.2 kg-cm^2)
Ignition time	0.013 second
I_{sp} (vacuum, based on propellant weight)	274.2 lb-sec/lb
Case temperature	400°F
Firing temperature limits	20° to 140°F
Explosive classification	ICC jet thrust unit, Class B explosive
Storage temperature limits	20° to 130°F
Estimated storage life	1 year at 80°F

Table 3-1 (continued)

Parameter	Characteristic
Igniter	
Circuit	Two bridges
Resistance	1.1 to 1.3 ohms
Normal firing current	4.5 amperes at 24 to 30 volts dc
No-fire current	1 ampere, 1 watt for 5 minutes each circuit
Hazard classification	ICC Class B explosive
Autoignition temperature	850°F

added precaution, the execute pulse must be at least 3 seconds long.

4) If for some reason the motor does not ignite when the fire command is executed, the command may again be sent and executed. If this fails, the redundant decoder and firing circuit may be used.

Inclination Removal Analysis

To remove inclination (i) from a circular synchronous orbit, the added velocity increment required is approximately equal to

$$\Delta V \sim 2V_o \sin\left(\frac{i}{2}\right) \qquad (1)$$

where V_o is the synchronous orbit velocity and i is the change in inclination in degrees. Therefore,

$$\Delta V(\text{fps}) = (2.0166)(10^4) \sin\left(\frac{i}{2}\right)$$

Figure 3-2 shows the final inclination as a function of ΔV, assuming the initial orbit is synchronous with a 28.5 degree inclination.

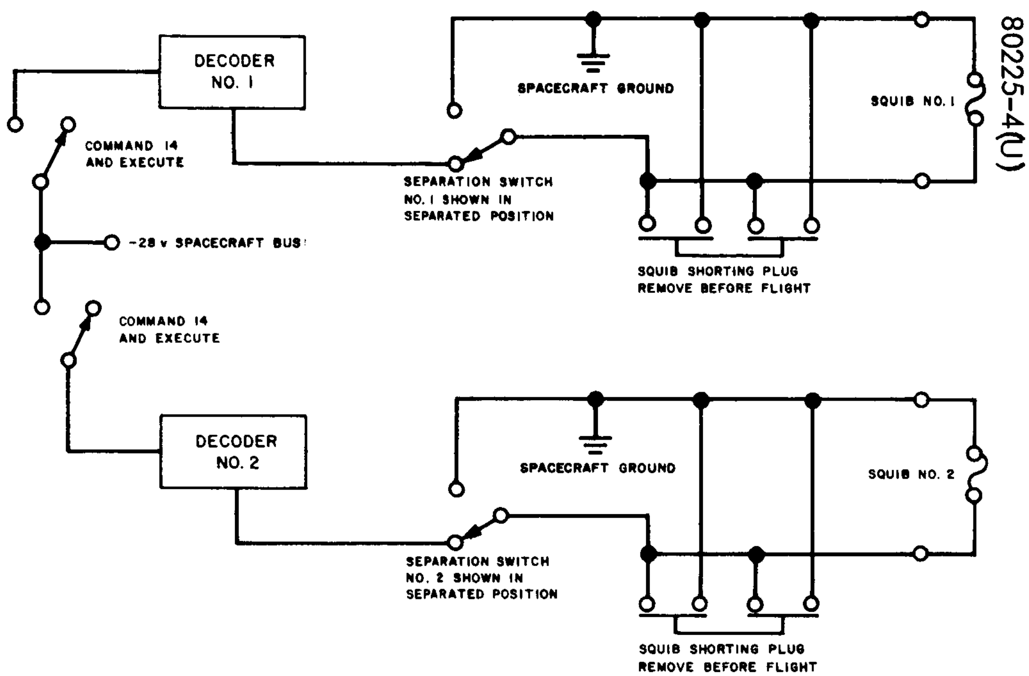


Figure 3-1. Squib Firing Circuit

The velocity increment obtained by an IBS with the Early Bird apogee motor (60.5 pounds of propellant) is related to the IBS ignition weight through

$$\Delta V = g I_{sp} \ln\left[\left(\frac{Wi}{Wi} - 60.5\right)\right] \qquad (2)$$

Figure 3-3 shows the ΔV obtained as a function of the IBS burnout weight.

Using the I_{sp} of 274.2 for the JPL Syncom apogee motor, assuming an initial satellite final orbit weight of 78.77 pounds, allowing 1.11 pounds for apogee motor expendables, and 0.7 pound of nitrogen for satellite spinup, the velocity increment achieved from the apogee boost will be (from Equation 2)

$$\Delta V_{AP} = 4950 \text{ fps}$$

From Equation 1 the velocity increment required to remove 28.5 degrees inclination from a synchronous orbit is

$$\Delta V_{REQ} = 4950 \text{ fps}$$

Thus, the Syncom apogee motor provides a perfect match to achieve a stationary orbit with the IRIBS. The change in velocity required as a function of satellite weight is given by 47 fps/lb. With minor weight changes, an excess or deficiency of apogee boost will exist. Spin axis misalignment or apogee boost thrust errors will also cause the post-boost orbit to deviate from the stationary. However, the on-board hydrogen peroxide may be used to correct these errors and still leave sufficient fuel for long-term stationkeeping. The problem of achieving the correct pre-boost attitude is discussed below.

Inclination Removal Firing Attitude

The attitude required for apogee motor firing, such that the velocity increment produces a stationary orbit, corresponds to a declination of 75.8 degrees and a flight path angle of zero, i.e., the spin axis is in a plane normal to the radius vector. The velocity triangle is illustrated in Figure 3-4. Before separation from the Apollo vehicle, the spin axis will be aligned in the proper attitude with negligible error. The spacecraft separation will induce some attitude error, which can be kept to under 0.5 deg/sec of time elapsed prior to spinup. If spinup is initiated within 2 seconds, the total attitude error should be under 1 degree.

The apogee boost must occur when the satellite is at the equatorial crossing to remove the inclination. Separation and spinup will occur some time, perhaps several hours, prior to the crossing if a large spacecraft separation from the Apollo vehicle is required.

Spacecraft attitude may be determined from the sun sensor data telemetered to the ground station. However, since these data provide only one coordinate of the spin axis attitude, many days are required to obtain an accurate attitude determination. This is because the sun's motion is necessary to obtain the second attitude determining coordinate. Assuming a 1σ error, ϵ, in the sun angle readings, the attitude accuracy ΔS achievable in N days is approximately given by

$$\Delta S = \left(\frac{29\epsilon}{N}\right)$$

Errors in the sun angle readings may be caused by noisy data or sensor misalignments. A value of ϵ equal to 0.2 degree is estimated for the IRIBS. Thus, 6 days would be required to confirm the apogee boost attitude to within 1 degree. Since the expected attitude error is on the order of only 1 degree, it will not be necessary to confirm the attitude by a pre-boost attitude determination. The increased apogee boost accuracy obtained from a small touch-up reorientation prior to boost does not warrant the long necessary delay. Since sun angle data immediately provide one component of spin axis attitude, this component could be corrected by a small pre-apogee boost reorientation, thus reducing the on-station peroxide requirements.

The required spin axis declination of 75.8 degrees corresponds to an angle between the spin axis and the earth's polar axis of 14.2 degrees. Thus the angle α between the ecliptic and the spin axis

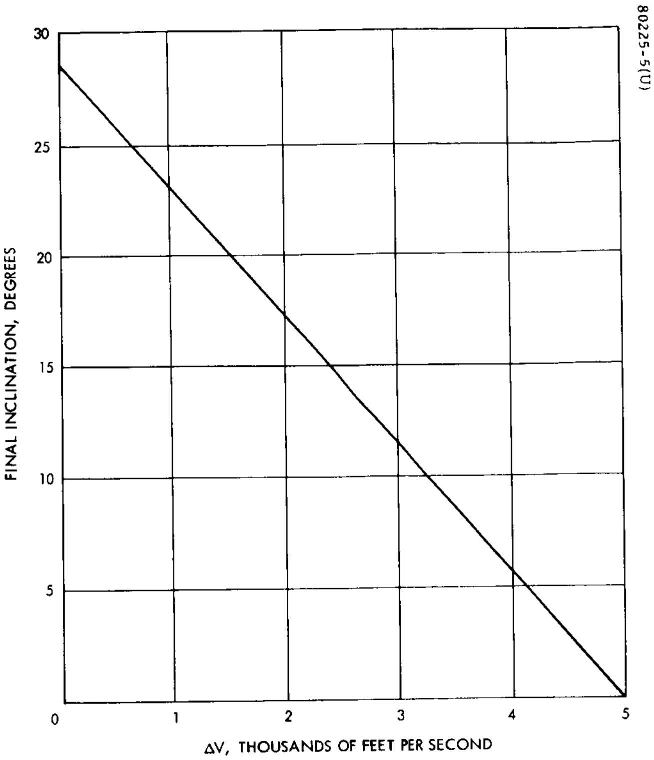


Figure 3-2. IRIBS Final Inclination Versus Apogee Motor ΔV

Initial 28.5 degree inclination synchronous orbit

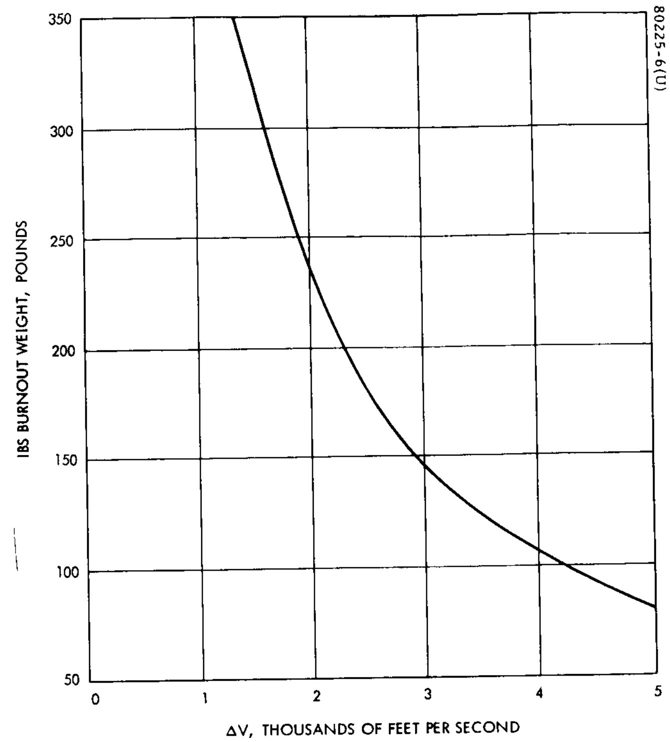


Figure 3-3. ΔV Versus IRIBS Burnout Weight

Early Bird apogee motor

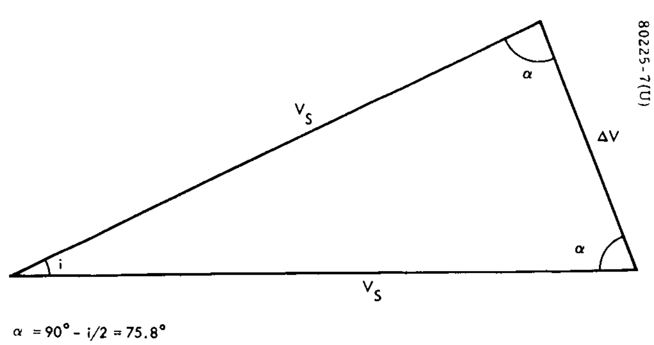


Figure 3-4. Velocity Triangle for Inclination Removal

will be somewhere between 9.2 and 36.6 degrees, depending on the spin axis right ascension. The latter is dependent on both launch time and date. Since α is a measure of the maximum deviation of the sun angle ϕ from 90 degrees, values of α greater than 30 degrees will correspond to ϕ greater than 120 degrees at certain times of the year and less than 60 degrees at other times. Power and thermal considerations suggest avoiding such ϕ angles even though they will exist only from spacecraft separation through the post-boost reorientation (which will correspond at most to a few hours). Launch times must therefore be restricted for up to a 3 month period. The restrictions should amount to a maximum of 4 hours a day at worst launch date. These constraints could be eliminated by a planned post-deployment attitude change.

Boost Errors and Peroxide Corrections

Errors in the apogee boost magnitude or direction, i.e., thrust errors or attitude misalignment, will cause errors in the post-boost orbit. Subsequent hydrogen peroxide corrections will remove these errors. The peroxide will also be used to induce and then remove drift to place the satellite at the desired longitude to reorient the spin axis normal to the orbit plane and to provide stationkeeping. For an antenna pointing northward, the reorientation will be through 166 degrees, requiring about 0.8 pound of hydrogen peroxide. A nonsynchronous target orbit may be used to cause a desired initial drift by modifying the desired attitude. Inducing or removing drift requires 9.3 fps of velocity (about 0.2 pound of peroxide) per degree of drift per day.

An apogee motor thrust error, ΔV_B, produces velocity increment errors ΔV_N normal to the final orbital plane and ΔV_T tangential to the final velocity vector given by

$$\Delta V_T = \Delta V_\beta \cos \alpha = 0.24 \; \Delta V_B$$

$$\Delta V_N = \Delta V_\beta \sin \alpha = 0.97 \; \Delta V_B$$

An error in the spin axis declination $\Delta\theta$ produces corresponding errors given by

$$\Delta V_T = V_\beta (\sin \alpha) \Delta\theta = 84 \text{ fps/deg}$$

$$\Delta V_N = V_\beta (\cos \alpha) \Delta\theta = 21 \text{ fps/deg}$$

An error in the spin axis right ascension $\Delta\alpha$ produces an erroneous radial component of velocity ΔV_R given by

$$\Delta V_R = V_\beta \Delta\gamma = 87 \text{ fps/deg}$$

Assuming 3σ errors of 1 degree in each component of spin axis attitude and 1 percent (50 fps) in apogee boost, these relationships imply a velocity increment of 110 fps, or slightly over 2 pounds of hydrogen peroxide to achieve the stationary orbit. This assumes the radial velocity error is corrected, using a more economical method of applying a tangential impulse 90 degrees later in the orbit.

Thus, even in the presence of worst-case apogee boost errors, the IRIBS can be placed on station in a stationary orbit and still retain about 7 pounds of hydrogen peroxide for control. This is primarily due to the excellent match of the Apollo orbit, IRIBS weight, and JPL Syncom motor. Once on station, east-west stationkeeping will require, at most, 6 fps per year of velocity increment. Solar and lunar perturbations will cause an orbital inclination buildup at an average rate of about 0.9 degree per year. It would require a velocity increment of 160 fps (on the order of 3 pounds of hydrogen peroxide) per year to completely remove the inclination buildup. However, due to the relatively small inclination buildup, the IRIBS will probably not require north-south stationkeeping. By properly selecting the initial inclination at about 1.5 degrees, the inclination would decrease to 0 degree and then increase to 1.5 degrees in the opposite direction over a 3 year period. Thus the inclination could be kept to within ±1.5 degree over a 3 year period.

IRIBS DESIGN SUMMARY

This subsection describes the design modification required to convert the IBS configuration described in Reference 1 into the IRIBS satellite. The Early Bird apogee engine has been retained in the IRIBS configuration and, with the exception of the beacon antenna, is identical to the Early Bird satellite. The IRIBS general arrangement is shown in Figure 3-5. Other basic changes made to the IBS are as follows:

1) The antenna length was decreased.
2) The beacon antenna was relocated to the separation end of the spacecraft.
3) The antenna support structure was redesigned.
4) The spin-up system was redesigned and relocated.
5) The balance and ballast weight was reduced to 1.5 pounds.
6) The whip antennas were relocated.
7) The satellite support structure was redesigned.

The replacement of the apogee engine increases the satellite weight at separation by nearly a factor of 2, with the final orbit weight remaining unchanged. Several configurations utilizing the extended beacon antenna, as shown in Reference 1, were studied. The computed roll-to-pitch inertia ratios showed the satellite to be unstable, and that approximately 30 pounds would be required to stabilize the spacecraft. The addition of the required dead weight proved to be impractical and led to an alternate solution of reducing the length of the beacon antenna.

The shorter antenna length offers several advantages, the most important being the elimination of a large amount of balance weight necessary to obtain a roll-to-pitch inertia greater than one. The shorter antenna also allows the use of the separation system presently incorporated on the Early Bird satellite and assures a clean separation which would be difficult to obtain with the previous antenna configuration.

Relocating the antenna to the separation end of the spacecraft requires a minimum amount of change to the Early Bird structure. Support of the beacon antenna will be provided by a machined cone that attaches to a flange on the thrust tube. The antenna electronic packages will be rib mounted for easy access.

A two-tank spin-up system has been located in the vacant payload quadrants 1 and 3. The tank diameter needed for storing approximately 0.7 pound (0.317 kg) of nitrogen at 2500 psi (175.5 kg/cm^2) was calculated to be 4.6 inches (11.58 cm). The spin speed of the spacecraft was assumed to be 150 rpm. The weight of the two-tank system has increased approximately 1 pound (0.45 kg) over that shown in Reference 1. Since the spin-up method is different from the Early Bird satellite, a description of the system is included in this report.

Minimum changes to the Early Bird satellite structure will be required if the equipment carried by the spacecraft is located so that the resulting center of gravity after apogee motor firing passes through the center of the reaction control system tanks. The balance weight required to attain the desired center of gravity location is 1.5 pounds (0.68 kg). The present separated weight of the satellite is 142.58 pounds (64.58 kg) as compared to 149 pounds (67.5 kg) for Early Bird.

Telemetry and command antennas have been relocated at the apogee engine end of the spacecraft. Thus the mounting and location of the antennas will be the same as on Early Bird.

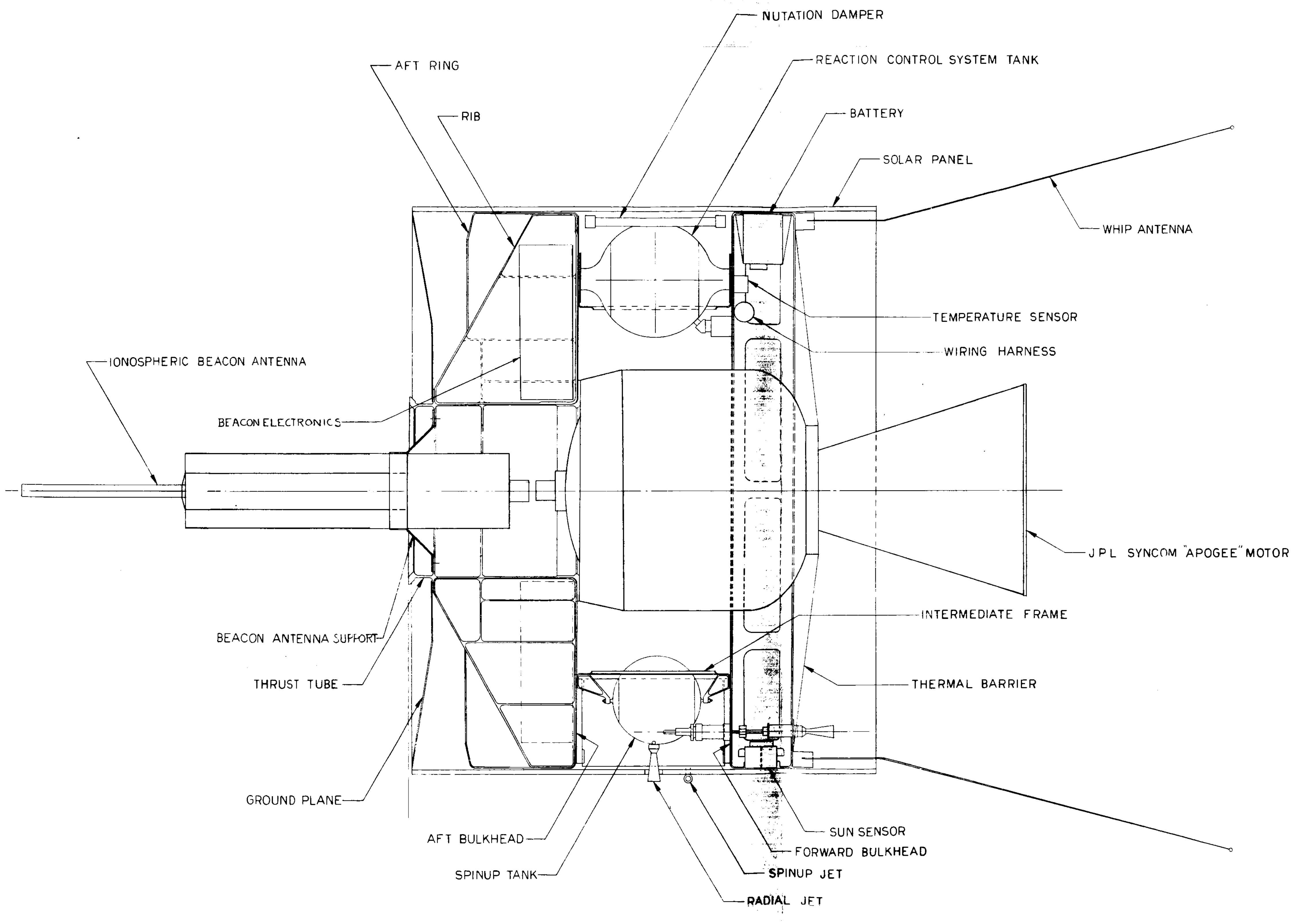
The spacecraft support structure will require redesigning because of the ionospheric beacon antenna location. A proposed structure is shown in Figure 3-6. The redesigned structure will weigh an additional 1.5 pounds (0.68 kg). A separation analysis of the present system indicates there is adequate clearance between the spacecraft adapter and beacon antenna. The analysis and relevant discussion are included later in this report.

The functions of the various structural elements, the description of the structure, and the spacecraft general arrangement are discussed in Reference 1 and will not be repeated here. A detailed description of the apogee engine, associated circuitry, and the engine characteristics are presented in the following subsections. A weight summary and table of mass properties are also included. Additional changes that would affect the Apollo interface are discussed later.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3



COMPONENTS ROTATED FOR CLARITY

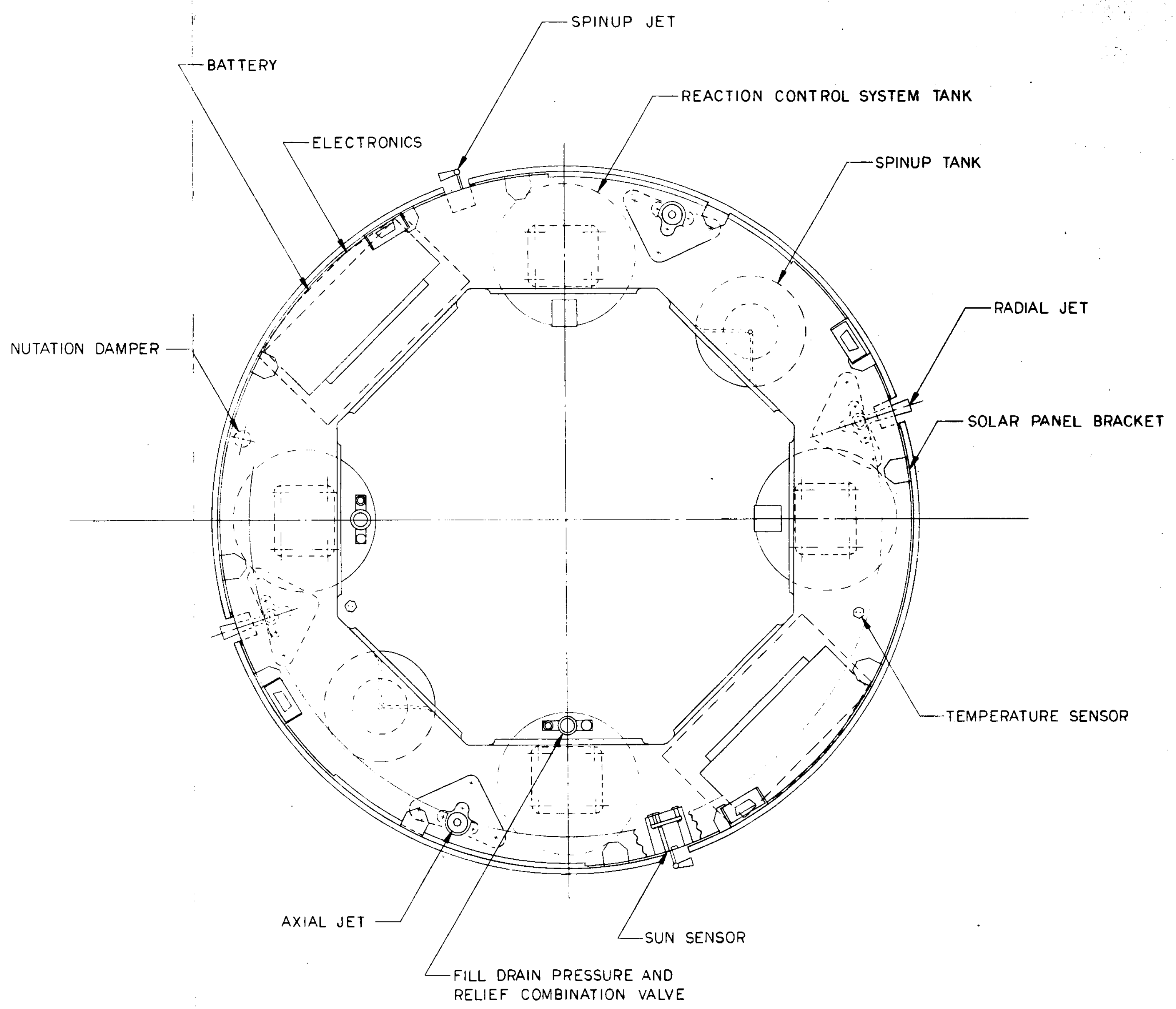


Figure 3-5. IRIBS General Arrangement

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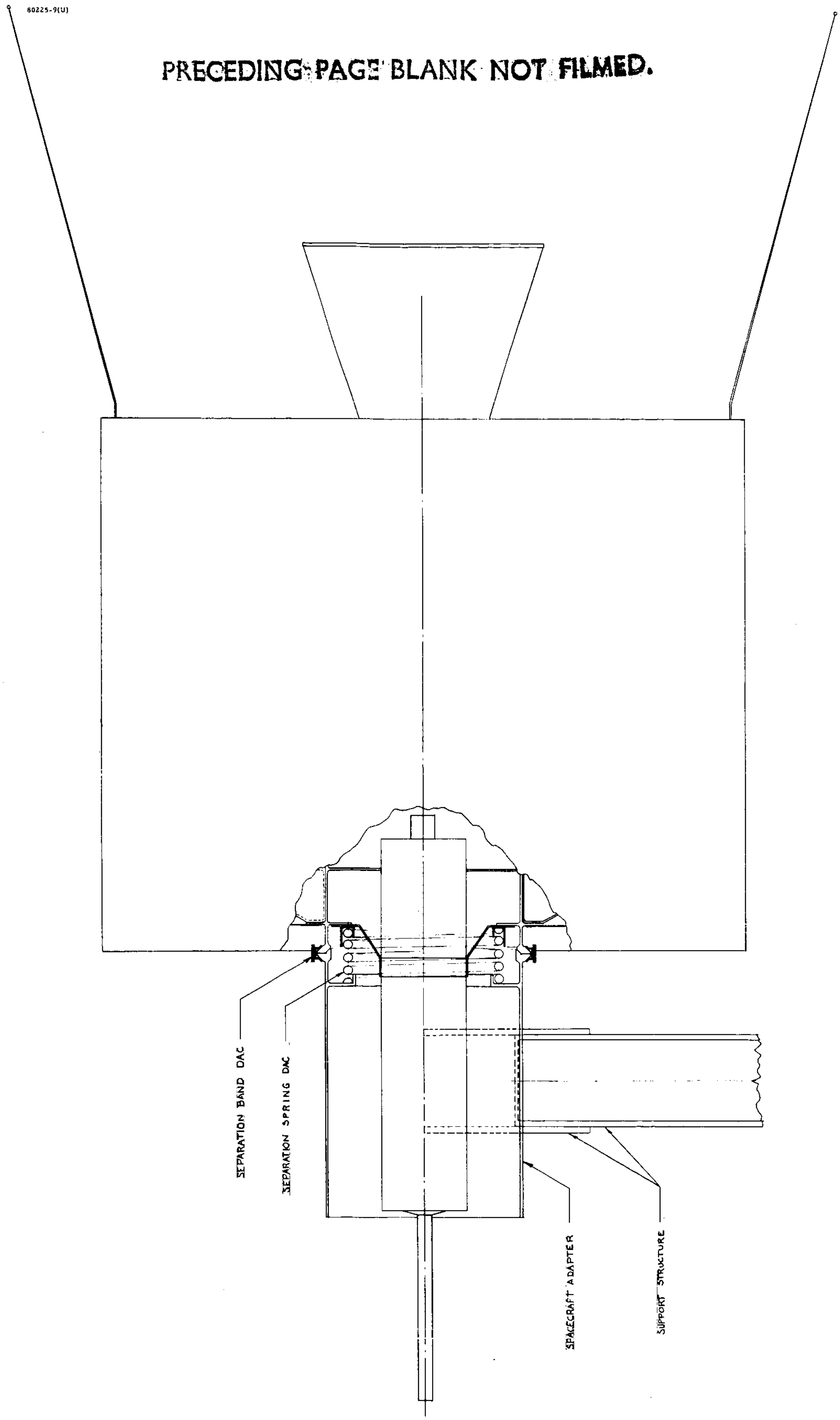


Figure 3-6. IRIBS Separation System

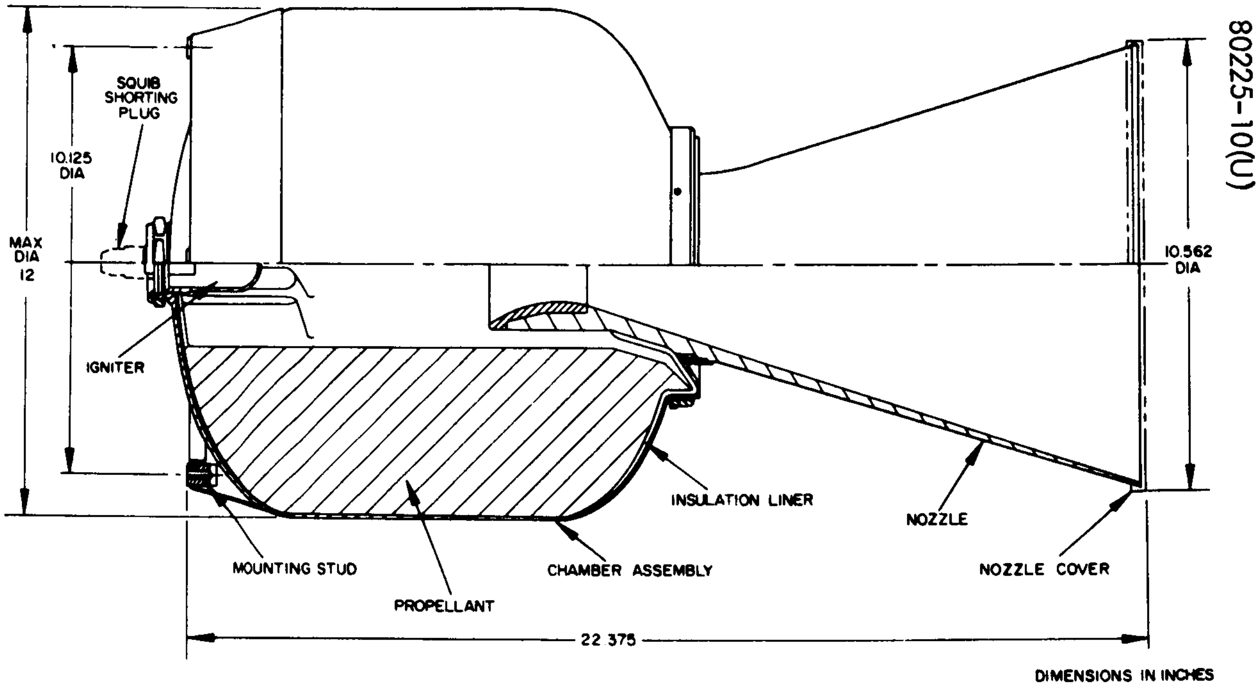


Figure 3-7. JPL Syncom Motor

Inclination Removal Motor

For the IRIBS to achieve a synchronous equatorial orbit, a velocity increment, in addition to the velocity imparted by the Apollo vehicle, must be given to the spacecraft. This increment is added largely by the Early Bird apogee motor. Additional velocity correction capability must be available to achieve and maintain stationkeeping because of uncertainties that exist in velocity increments imparted by both the launch vehicle and the apogee motor. The hydrogen peroxide control unit provides this corrective capability.

The JPL Syncom motor fits the inclination removal requirement and is an ideal selection because it was used for the Early Bird launch. Figure 3-7 shows an outline of this engine, and its characteristics are listed in Table 3-1. The thrust of the apogee engine is transmitted to the spacecraft through an attachment ring brazed to the forward elliptical surface of the motor case. No other contact exists between the case and spacecraft structure or components except for the thin aluminized fiberglass radiation barrier.

Weight Summary

A weight summary of the IRIBS satellite is presented in Table 3-2. It differs from the weight summary given in Table I.8-1 of Reference 1 in the following ways:

1) Ionospheric beacon antenna — The reduced length of the antenna reduces satellite weight by approximately 50 percent. The present antenna weight estimate is 0.69 pound (0.31 kg).
2) Balance and ballast — The balance and ballast weight has been reduced from 12.0 pounds (5.43 kg) to 1.5 pounds (0.68 kg). The addition of the apogee motor case and the reduced length of the ionospheric beacon antenna significantly affected the balance and ballast weight required for the desired center of gravity location and the roll-to-pitch inertia ratio.

TABLE 3-2. IRIBS WEIGHT SUMMARY

Unit	Unit Weight, pounds	Total Weight, pounds
Ionospheric beacon transmitter	3.0 (1.36 kg)	3.0 (1.36 kg)
Ionospheric beacon antenna	0.69 (0.31 kg)	0.69 (0.31 kg)
Quadrants 2 and 4	3.46 (1.56 kg)	6.92 (3.13 kg)
Receiver regulator		
Command discriminator		
Postamplifier		
Attenuator		
Telemetry transmitter		
Telemetry regulator converter		
Encoder		
Decoder		
Auxiliary equipment		
Hydrogen peroxide system 1		3.95 (1.79 kg)
Hydrogen peroxide system 2		3.89 (1.76 kg)
Hybrid balun		0.27 (0.122 kg)
Whip antenna assembly	0.16 (0.07 kg)	0.64 (0.29 kg)
Temperature sensor	0.02 (0.009 kg)	0.04 (0.018 kg)
Battery, 11-cell (2)	1.25 (0.565 kg)	2.50 (1.13 kg)
Battery, 10-cell (2)	1.205 (0.545 kg)	2.41 (1.09 kg)
Solar panel (4)		9.15 (4.14 kg)
Structure		12.44 (5.64 kg)
Nutation damper		0.13 (0.059 kg)
Solar sensor (2)	0.18 (0.081 kg)	0.36 (0.163 kg)
Wiring harness		3.63 (1.64 kg)
Ground plane		0.43 (0.19 kg)
Radiation barrier		0.46 (0.208 kg)
Balance and ballast		1.5 (0.68 kg)
Beacon support		0.5 (0.34 kg)
Spin-up tanks and equipment		5.63 (2.54 kg)
Apogee engine case and hardware		9.87 (4.46 kg)
Miscellaneous		2.0 (0.91 kg)
Final orbit weight		68.91 (31.3 kg)
H_2O_2 expendables		9.86 (4.46 kg)
Initial orbit weight		78.77 (35.65 kg)
Apogee engine propellant and expendables		61.61 (27.9 kg)
N_2 (spinup)		0.7 (0.317 kg)
Spacecraft at separation		142.58 (64.58 kg)

3) Beacon support structure — Relocating the beacon antenna to the separation end of the spacecraft eliminated the long conical beacon support structure. A weight savings of approximately 2 pounds (0.91 kg) was realized.

4) Spin-up tanks and equipment — The two-tank system used in the modified design weighs an additional 1 pound (0.45 kg) because of the necessary bracketing and manifolding, and increased tank weight.

5) Apogee engine case and hardware — This unit has been added to the spacecraft. No additional hardware beyond what was used on Early Bird will be required for its installation.

6) Miscellaneous — Two pounds (0.91 kg) are assumed to cover such items as paint, screws, insulation, etc.

The final orbit weight of the modified satellite is 69.41 pounds (31.98 kg) as compared to 69.27 pounds (31.35 kg) for the configuration shown in Reference 1. Launch weight, however, is significantly different due to 61.61 pounds (27.9 kg) of apogee engine propellant carried by the engine.

Mass Properties

Estimates of the total weight, center of gravity locations, and mass moment of inertia about roll and pitch axes of the spacecraft at separation, initial orbit, and final orbit are shown in Table 3-3. Should additional experiments be placed on the satellite, the payload must be restricted so that the center of gravity location does not change by more than 0.25 inch and that I_{roll}/I_{pitch} remains >1.04. A comparison of Table 3-3 with Table I.8-2 of Reference 1 indicates that the IRIBS configuration is more stable in all conditions.

TABLE 3-3. IRIBS MASS PROPERTIES

State	Weight, pounds	Center of Gravity Z, inches	Moments of Inertia		
			I_{zz} (roll), lb-in^2	I_{xx} (pitch), lb-in^2	I_{zz}/I_{xx}
Final orbit	69.41 (31.98 kg)	12.4 (31.5 cm)	7160 (20900 kg-cm^2)	6513 (19000 kg-cm^2)	1.099
Initial orbit	80.27 (36.33 kg)	12.4 (31.5 cm)	8490 (24750 kg-cm^2)	7177 (20950 kg-cm^2)	1.183
At separation	142.58 (64.58 kg)	13.14 (33.4 cm)	9635 (28100 kg-cm^2)	8406 (24520 kg-cm^2)	1.146

Separation-Antenna Clearance

At satellite separation from the Apollo vehicle the motion of the antenna must be determined so that adequate clearance is maintained between the antenna and spacecraft adapter. Two points on the antenna are considered: the tip of the antenna and the point at which the large diameter of the antenna terminates. The position of the points in question can be described by the equation

$$X_p = V_s t \rightarrow L\omega t$$

where

V_s = spacecraft separation velocity
L = distance from center of gravity to point of interest
ω = spacecraft tip-off rate

For a separation velocity of 4 fps (1.22 m/sec), the time required for the antenna to clear the spacecraft adapter is $t = 19.5/48 = 0.406$ second. A 1.5 degree tip-off rate is assumed with $L_1 = 32.6$ inches (82.8 cm) and $L_2 = 24.5$ inches (62.2 cm), with L_1 and L_2 being measured from the spacecraft center of gravity at separation.

The value of the separation velocity is made intentionally low and the tip-off rate high. With care in selecting the separation springs, the tip-off rate can be reduced to one-half the assumed value.

The calculations shown in Table 3-4 indicate that no interference will exist during spacecraft separation. The contribution of the tip-off rate to the displacement of the spacecraft is insignificant. Lower separation velocities and higher tip-off rates could be accommodated. The motion of the antenna during separation is shown in Figure 3-8.

Spin-Up Subsystem

Various systems may be employed to spin up a satellite. On the Early Bird launches, a spin table was mounted between the second and third stages on ball bearings and spun up by a set of small solid propellant rocket motors. Spinning of the third stage payload combination stabilized the configuration during third stage burn.

The ATS program uses a free-body, cold-gas, blow-down spin-up system. A comparative study made for other space programs showed that the free-body spin-up approach appeared to offer only a small advantage over the spin table on a weight basis. Reliability considerations, however, made the cold-gas, free-body spin-up approach more attractive. Recent experience with the ATS launches confirmed the validity of this approach.

Hot gas was also considered as an energy source for free-body spinup; however, the exhaust plume is intolerably erosive on the solar cells. This intolerance is applicable to bipropellants as well as to solid rockets.

The cold-gas system does not contribute to the solar cell erosion or contamination problem; therefore, the nozzle can be located closer to the plane of the center of gravity. On the Ionospheric Beacon Satellite, the spin-up jets are located in the plane of the center of gravity 90 degrees from the radial jets. Existing openings between the solar panels provide a convenient location for the jet mounting.

TABLE 3-4. LINEAR AND ROTATIONAL TRAVEL OF BEACON ANTENNA*

t	$V_s t$, inches (cm)	ωt, rad/sec	L_1 = 32.6 inches (82.8 cm)		L_2 = 24.5 inches (62.2 cm)	
			$L\omega t$, inches (cm)	$V_s t \rightarrow L\omega t$	$L\omega t$, inches (cm)	$V_s t \rightarrow L\omega t$
0.05	2.4 (6.1)	0.00131	0.0427 (0.108)	2.400 (6.1)	0.0321 (0.082)	2.400 (6.1)
0.10	4.8 (12.2)	0.00262	0.0854 (0.217)	4.801 (12.2)	0.0642 (0.163)	4.800 (12.2)
0.15	7.2 (18.3)	0.00393	0.1281 (0.328)	7.201 (18.28)	0.0963 (0.244)	7.201 (18.3)
0.20	9.6 (24.4)	0.00524	0.1708 (0.434)	9.602 (24.4)	0.1284 (0.326)	9.601 (24.4)
0.25	12.0 (30.4)	0.00655	0.2135 (0.541)	12.002 (30.5)	0.1605 (0.407)	12.001 (30.5)
0.30	14.4 (36.6)	0.00786	0.2562 (0.651)	14.402 (36.56)	0.1926 (0.489)	14.401 (36.6)
0.35	16.8 (42.6)	0.00917	0.2989 (0.760)	16.803 (42.7)	0.2247 (0.571)	16.802 (42.7)
0.40	19.2 (48.7)	0.01048	0.3417 (0.867)	19.203 (48.8)	0.2568 (0.653)	19.202 (48.8)
0.45	21.6 (54.9)	0.01179	0.3844 (0.977)	21.603 (54.9)	0.2889 (0.734)	21.602 (54.9)

*$\omega = \frac{1.5}{57.3} = 0.0262$ rad/sec.

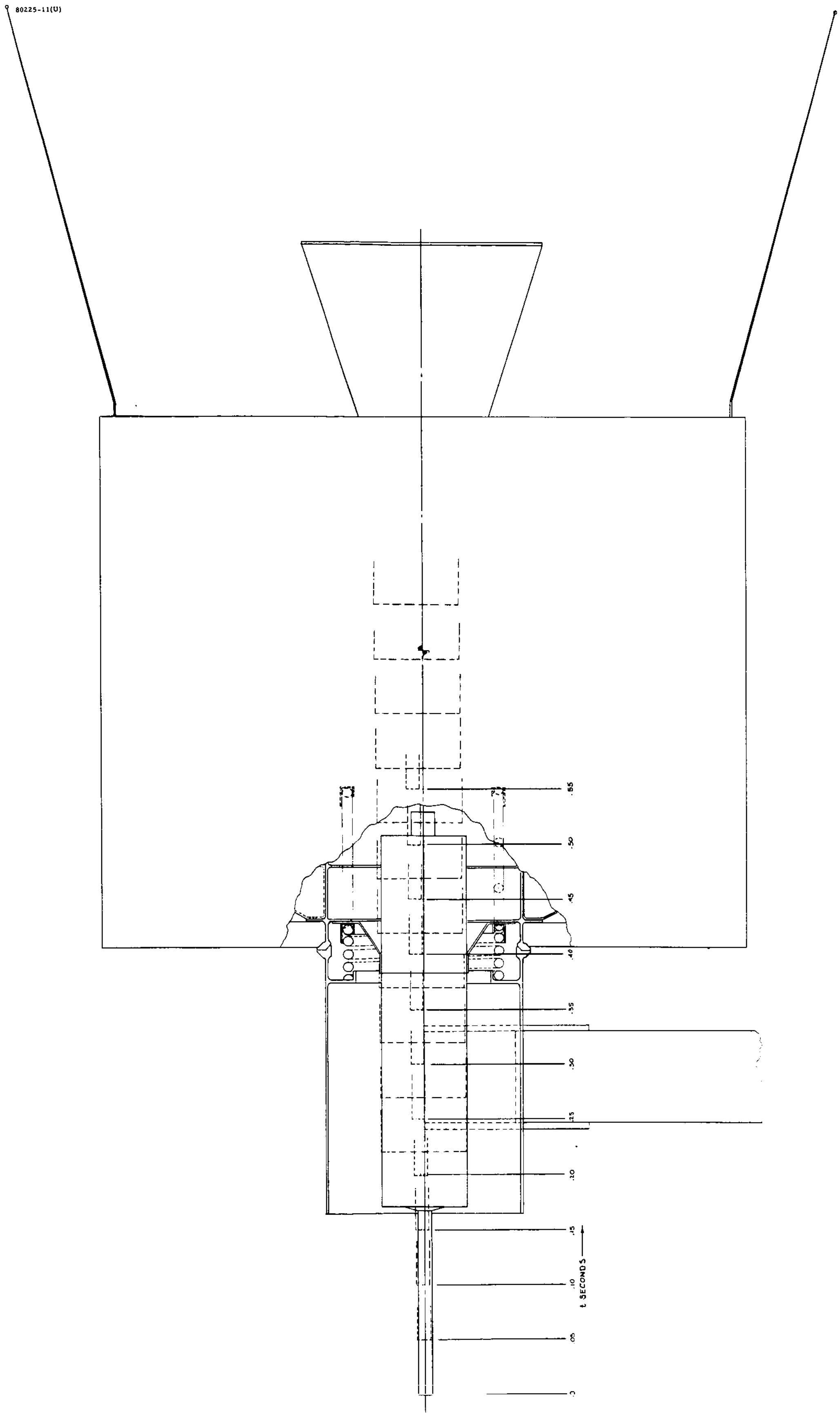


Figure 3-8. Antenna Motion During Separation

$$V_S = 4 \text{ fps} = 1.22 \text{ m/sec}$$
$$\omega = 1.5 \text{ deg/sec}$$

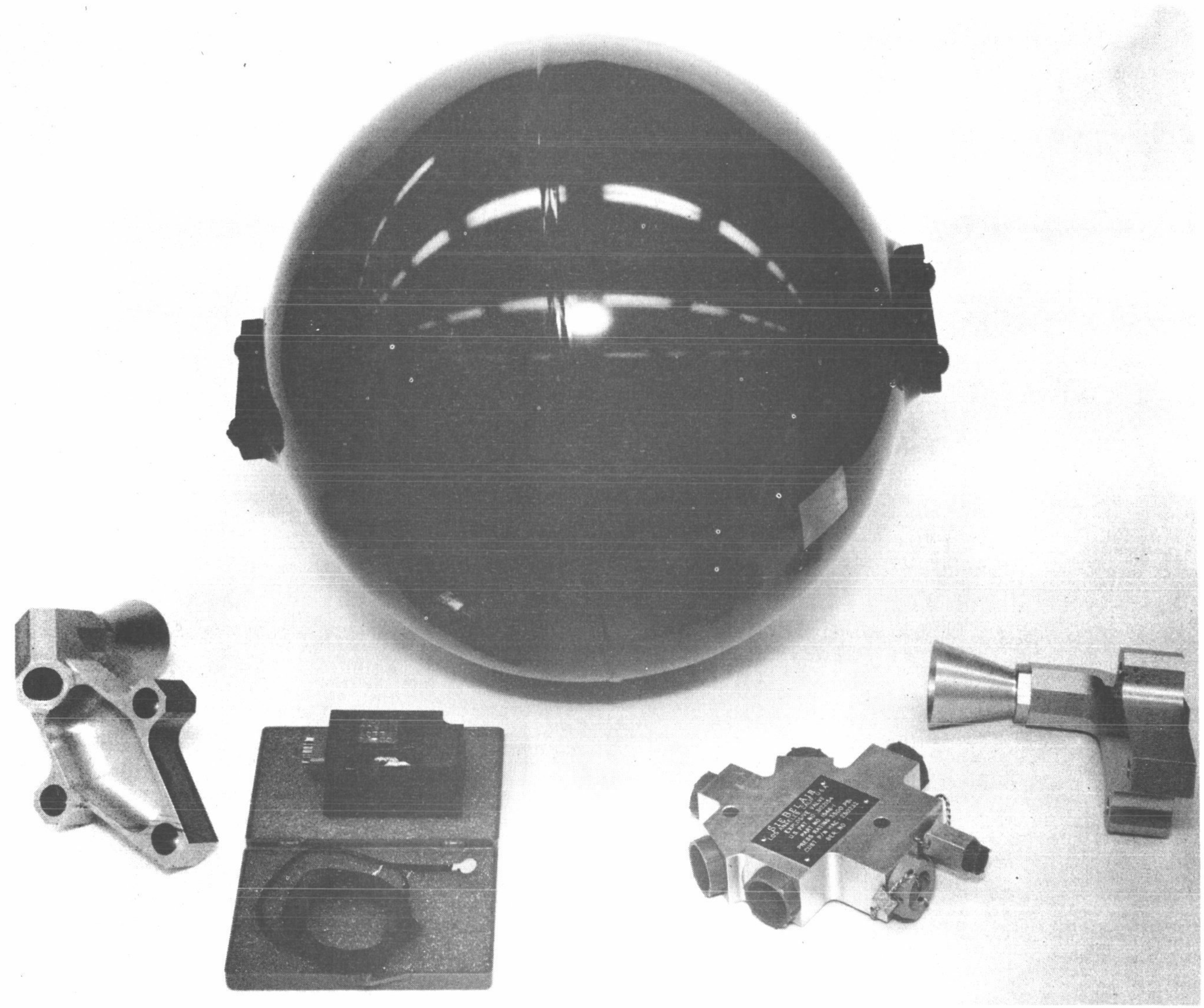


Figure 3-9. Spin-up System Components (Tank, Nozzles, Squib Valve, and Strain Gauge Amplifier)

The free-body spin-up function will be provided with a pair of tangentially located cold-gas nozzles mounted in the plane containing the spacecraft center of gravity at separation. This system will operate in a blow-down mode, thereby providing a simple and reliable means of spinning up the vehicle.

The tanks will be pressurized to 2500 psia. Two squib valves, redundantly connected for high reliability, will be opened by a command signal. This signal will be provided by microswitches attached at the separation plane on the spacecraft and bearing on the spacecraft adapter. Symmetrical plumbing to the nozzles will be used to assure a reasonably pure spin-up couple.

Figure 3-9 shows the components of a spin-up system. The strain gauge amplifier is used to check the pressure of the system prior to spacecraft separation. A mockup of the system is shown in Figure 3-10.

The impulse required to spin up the satellite may be determined from

$$T = I_{zz}\alpha$$

where

T = torque = force x distance
I_{zz} = mass moment of inertia about spin axis
α = angular acceleration

The spin speed of the satellite is ω = 150 rpm = 5π rad/sec. I_{zz} = 2.5 slug-ft^2 at separation.

Assuming the spin speed will be reached in 1 second, and $\alpha = \Delta\omega/\Delta t$, Equation 3 can be written as:

$$F \cdot R \cdot \Delta t = I_{zz} \Delta\omega \tag{4}$$

The required impulse is then given by

$$I = F \cdot \Delta t = I_{zz} \Delta\omega/R \tag{5}$$

where R = 14-inch radius (35.6 cm).

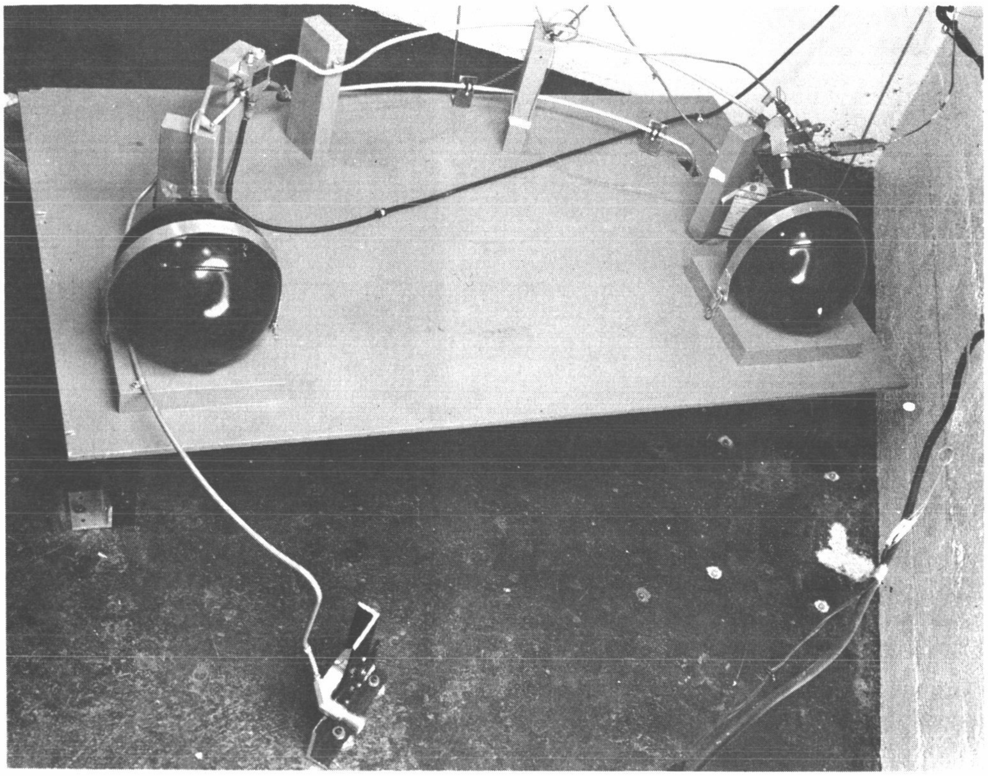


Figure 3-10. Mockup of Spin-up System

Substituting into Equation 5

$$I \text{ (lb-sec)} = 2.5 \text{ (slug-ft}^2\text{) } 5\pi \text{ rad/sec}^2 \times 1 \text{ second/(14/12) feet}$$

$$= 33.65 \text{ lb-sec (15.28 kg-sec)}$$

For an N_2 spin-up system. I_{sp} = 48.5 seconds. Therefore, the weight of required N_2 equals

$$\frac{33.65}{48.5} = 0.695 \text{ pound (0.315 kg)}$$

Tank size will be effected by the pressure in the system. A pressure of 2500 psi (175.5 kg/cm^2) is presently used on the ATS spacecraft and will be used here. From the ideal gas equation,

$$PV = WRT$$

where

P = pressure (absolute)

V = volume

W = weight of gas

R = gas constant

T = absolute temperature

$$V = 0.695 (55.1) \times 12 (540)/2500$$
$$= 99.3 \text{ cubic inches (1627 cubic cm)}$$

For a two-tank system, the diameter of the tanks is

$$D = \left[0.5(99.3)\ \frac{6}{\pi}\right]^{1/3}$$
$$= 4.56 \text{ inches (11.58 cm)}$$

When calculating the weight of the tanks, assume steel will be used with an allowable stress of 100,000 psi. A burst factor of 3 will be used. The thickness required is

$$t = \frac{3\ PD}{4\sigma}$$

where

$$P = 2500 \text{ psi } (175.5 \text{ kg/cm}^2)$$
$$D = 4.56 \text{ inches } (11.58 \text{ cm})$$
$$\sigma = 100,000 \text{ psi } (7020 \text{ kg/cm}^2)$$

Therefore,

$$t = \frac{3(2500)(4.56)}{4(100,000)} = 0.0856 \rightarrow 0.086 \text{ inch } (2.18 \text{ mm})$$

The weight of the tanks is

$$\text{Weight} = 2\pi D^2 t P = 2\pi(4.56)^2 (0.086)\ 0.283$$
$$= 3.23 \text{ pounds } (1.463 \text{ kg})$$

The spin-up system weight breakdown in pounds is as follows:

Tanks	3.23
Supports	0.50
Jets	0.45
Squib valve	0.75
Amplifier	0.40
Plumbing	0.30

Total estimated weight is 5.63 pounds (2.55 kg).

Electrical Power Requirements

The electrical power requirements of the spacecraft components are summarized in Table 3-5. The demands are given as load currents which must be provided by the unregulated bus. The minimum input voltage to the various regulators is 24.5 volts. Receivers, encoders, and decoders are on continuously from Apollo separation. All other loads will be keyed on and off by command.

TABLE 3-5. POWER DEMANDS SUMMARY

Load Condition	Current Demand, amperes (24.5 volts)	Power Demand, watts (24.5 volts)
Continuous loads		
Two receivers	0.250	6.1
Two encoders	0.024	0.6
Two decoders	0.004	0.1
Keyed loads (for one or two similar units)		
VHF telemetry transmitter	0.280	6.9
Beacon transmitter	0.694	17.0
Hydrogen peroxide jet solenoids (each)	0.450	11.0
Normal load during operation as Ionospheric Beacon Satellite with two receivers, encoders, decoders, one beacon transmitter, and one telemetry transmitter	1.252	30.7
Maximum power available (output of array, sun normal to spin axis)	1.89	46.5
Minimum power available (3 year radiation degradation and sunline 23.5 degrees to spin axis normal)	1.32	32.5

When the satellite has been placed in its final orbit, the beacon transmitter, other payload experiments, and either or both VHF telemetry transmitters may be operated on command. When the satellite is eclipsed by the earth, the receivers, encoders, decoders, and beacon transmitter will be operated by battery power.

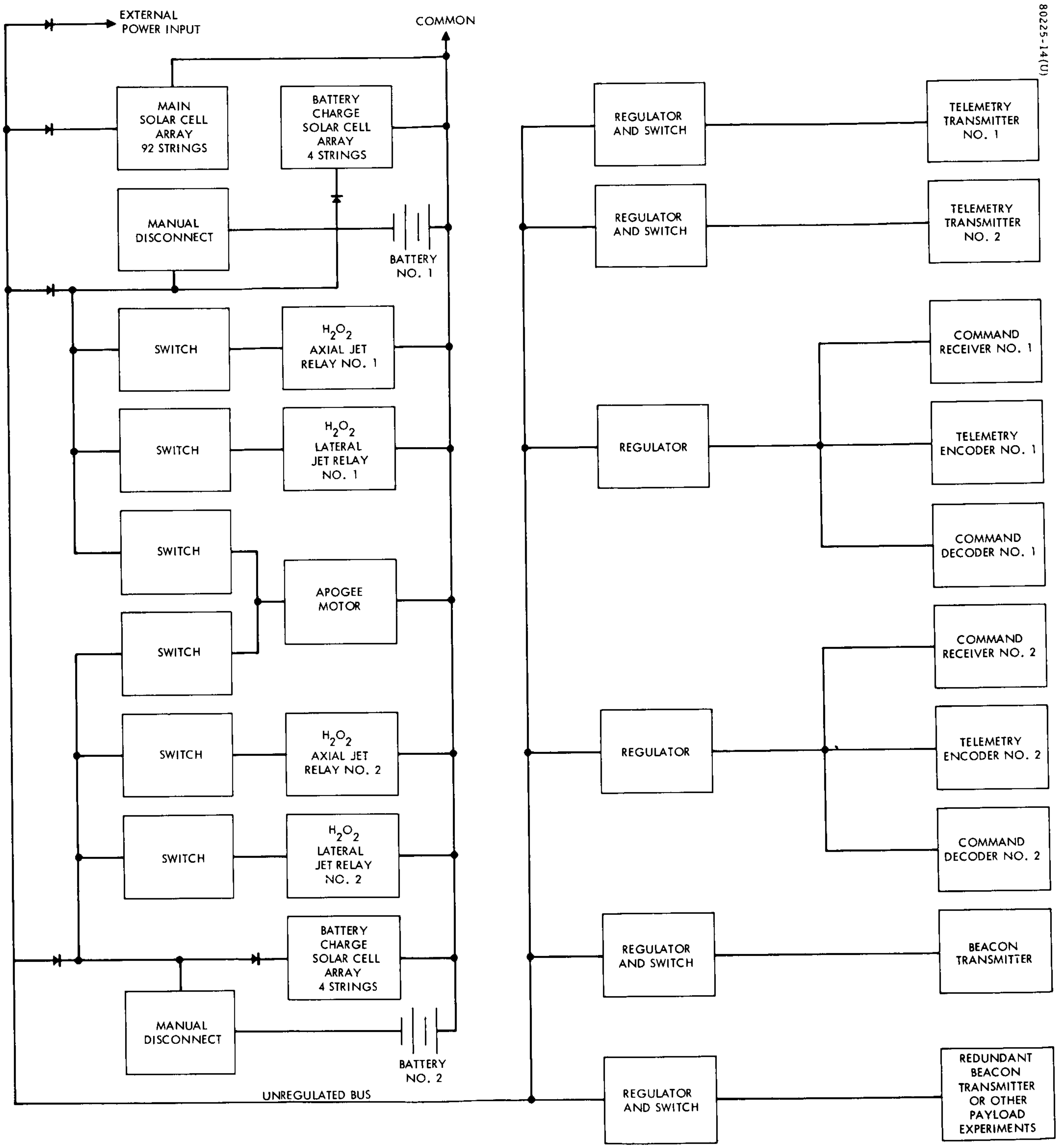


Figure 3-11. Power Supply Subsystem

In addition to the power requirements listed in Table 3-5, peak current loads are required for operation of the solenoid valves of the hydrogen peroxide control subsystem. The valves are connected directly to the battery to prevent loss of solar array power should these units fail "short" or in the ON position. The power supply block diagram is shown in Figure 3-11.

Other Payload Experiments

Weight and time share power available for other payload experiments has changed significantly from that shown in Reference 1. The volumes previously available in the central cylinder and quadrants 1 and 3 are now occupied by the antenna electronics and the spin-up tanks, respectively. The volume aft of the aft bulkhead, however, is still available (see Figure 3-12). The restriction on the added experiments is the effect on the satellite spin dynamics.

IONOSPHERIC BEACON ANTENNA SUBSYSTEM

The antenna shown in Figure 3-13 will serve the dual purpose of a 40-MHz short monopole and a 360-MHz skirted dipole. This antenna configuration is slightly different from the ones proposed in Reference 1 for the IBS satellite. The difference was caused by the addition of the apogee motor which, in turn, required that the antenna be moved to the end of the satellite interfacing with the Lunar Excursion Module rack. With the new antenna location, the method of satellite attachment to the Lunar Excursion Module rack and the mass moment of satellite inertia about the pitch axis become critical functions of antenna length. A short antenna is highly desirable for the above mechanical reasons. Therefore, a new and shorter antenna, which also appears to be electrically satisfactory, is proposed.

The skirted dipole at 360 MHz will have a radiation pattern essentially that of a half-wave dipole. This pattern is doughnut-shaped and has a 3-db beamwidth of approximately 80 degrees. Its peak gain is expected to be approximately 0 db relative to an isotropic radiator.

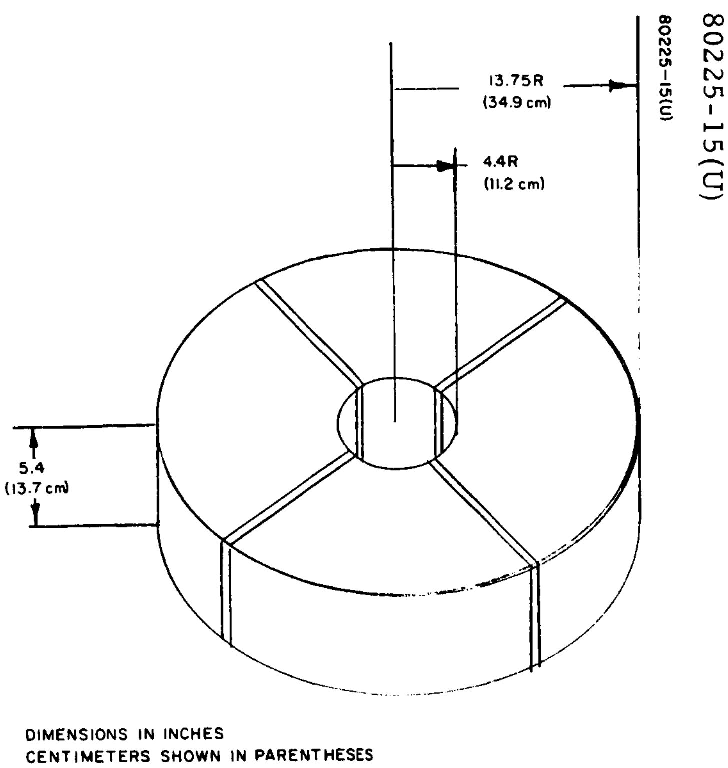


Figure 3-12. Volume Aft of Aft Bulkhead

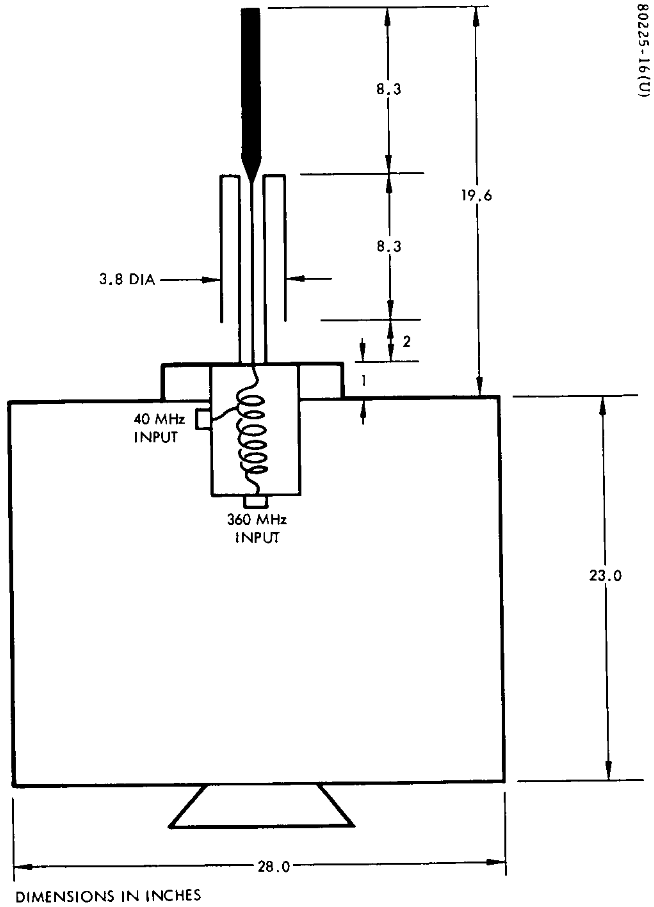


Figure 3-13. Ionospheric Beacon Antenna

The 360-MHz antenna is fed through a coaxial line (described below) which also serves as a matching coil for the 40 MHz antenna.

The skirted dipole will appear at 40 MHz like a short monopole (0.06 λ) above a very small ground plane. Except for a slightly larger beamwidth, its radiation characteristics at 40 MHz will be similar to those at 360 MHz. A short monopole has a large capacitive reactance and a small radiation resistance. Although a calculation of the reactive component of the monopole impedance is difficult without supporting measured data, it is estimated that the capacitive reactance of the antenna with the dimensions shown in Figure 3-13 is approximately 300 ohms. This capacitance will be tuned out with a matching coil inside a cavity. To keep the coil to a reasonable size, the geometry of the antenna will be adjusted experimentally to keep its capacitive reactance as low as possible. The approximate dimensions of a coil and cavity having a 300-ohm reactance are shown in Figure 3-14. The radiation resistance of the monopole at 40 MHz will be approximately 3 ohms. The series combination of radiation resistance and capacitive reactance is in parallel with the matching coil. The equivalent radiation resistance in parallel with the matching coil is very much larger than the desired input impedance of 50 ohms. Hence, it is possible to match the radiation resistance by tapping the coil at the point where its resistance to ground equals 50 ohms.

Mechanical Design

The mechanical portions of this antenna design present primarily structural and fabrication problems directly related to weight and its distribution. The electrical requirements of the antenna do not place any major hardship on the mechanical design; however, they do influence the mechanical design in the following ways:

1) The cavity (Figure 3-14) in which the two r-f lines come together must have good d-c continuity all around. Since this cavity is not in the critical weight area, almost any fabrication technique may be used, such as dip-braze, weld, etc. The connectors are standard and present no problems.

The matching coil will be made from a coax cable having a solid outer conductor in order to keep the losses at 40 MHz to a minimum.

2) The dipole (Figure 3-15) must have good d-c continuity and could be made from any good conducting material such as aluminum, magnesium, brass, etc. The dipole, then, becomes a problem of mechanical compromise between weight, structural integrity, fabrication technique, and cost.

3) The electrical portions of the antenna are not very useful as structure. The structural portions that contribute strength and stiffness must be independent of the electrical operation of the antenna. The most obvious answer to a good structure is a fiberglass sleeve bonded to the dipoles.

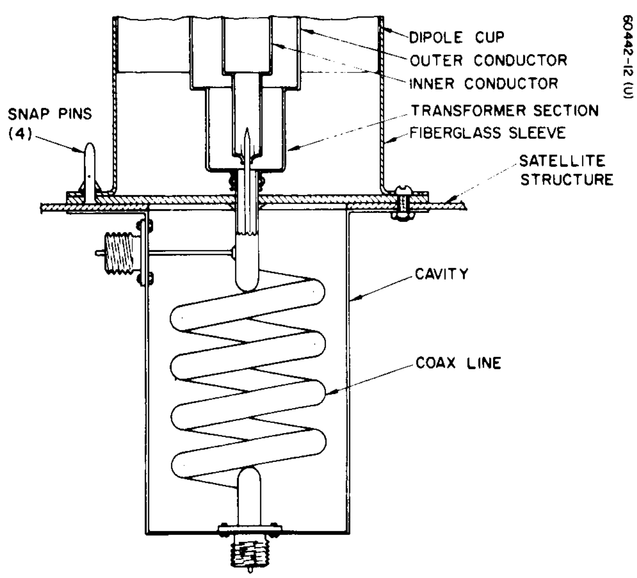


Figure 3-14. Cavity and Base of Antenna

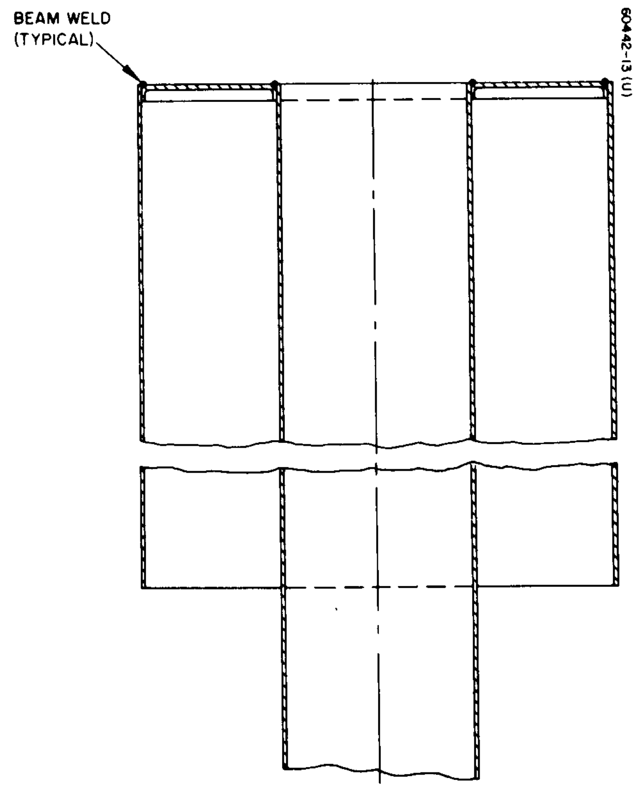


Figure 3-15. Dipole Cup

IONOSPHERIC BEACON ELECTRONICS

The ionospheric beacon subsystem contains the satellite equipment necessary to generate the required r-f signals for measurements at the ground stations. This involves generating signals at 40.01 mHz and 360.09 mHz with an option of amplitude modulation at 20 kHz. All frequencies are to be coherent.

This section discusses the requirements and a recommended system. Many of the requirements have been handled in previous Hughes experience. These will be related to the demands of the ionospheric beacon payload.

The basic requirements of the beacon payload are given in Table 3-6. From this, it can be seen that the generated power should be 1.5 watts at both 40.01 mHz and 360.09 mHz. Figure 3-16 shows how the required power and 65 to 85 percent amplitude modulation translates into a power spectrum. This assumes pure AM with no modulation distortion or carrier harmonic distortion.

Figure 3-17 shows a general block layout of what is required in the payload. While the 40.01 mHz, 360.09 mHz and 20 kHz generators are shown separate, it is obvious from the coherency requirement that they all be phase locked or derived from some common signal. It then becomes necessary to select the best system for relating the three frequencies.

The requirement of amplitude modulation with less than 10 percent harmonic distortion requires attention. As will be seen in the modulation section, a large range of attenuation of signal (up to 21 db) is required, and it is difficult to obtain linear attenuation over this wide a range. It is necessary to determine just how nonlinear the attenuation characteristic can be and still meet the 100 percent modulation harmonic distortion specification. This problem is complicated by the fact that power amplifiers tend to be somewhat non-linear and could further degrade the modulation linearity. This, too, must be considered.

A summary of the key parameters of the recommended system is as follows:

TABLE 3-6. TRANSMITTING EQUIPMENT REQUIREMENTS*

Coherent transmitting frequencies	40.01 mHz, 360.09 mHz
Relative phase jitter	1 radian/minute
Generated and radiated power (assuming 0 db antenna gain)	1.5 watts total power at both frequencies
Center frequency stability	$\pm$ 0.005 percent at each frequency
Modulation frequency (coherent with 40.01 and 360.09 mHz frequencies)	20 kHz
Modulation type	Amplitude modulation
Percentage of modulation	65 to 85 percent
Modulation harmonic distortion	10 percent
D-C input voltage	24 $\pm$ 1 percent
RFI requirements	Spurious and harmonics 50 db below carrier levels
Incidental FM	0.5 kHz at 40.01 mHz
Telemetry points	Power output and temperature
Telemetry voltage	0 to -5 volts
Control	Power ON - OFF for either output frequency Modulation ON - OFF for either output frequency

*Total required d-c power	10.87 watts
Weight	3.0 pounds
Approximate module volume	56 cubic inches

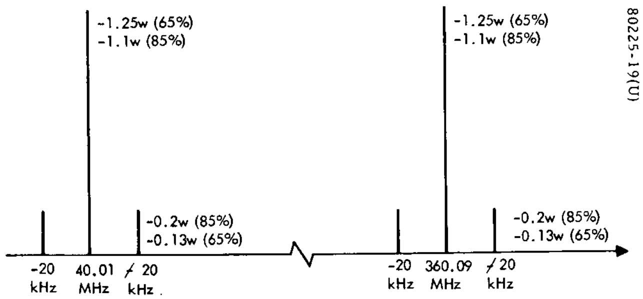


Figure 3-16. Generated and Radiated Spectrum for 65 and 85 Percent Amplitude

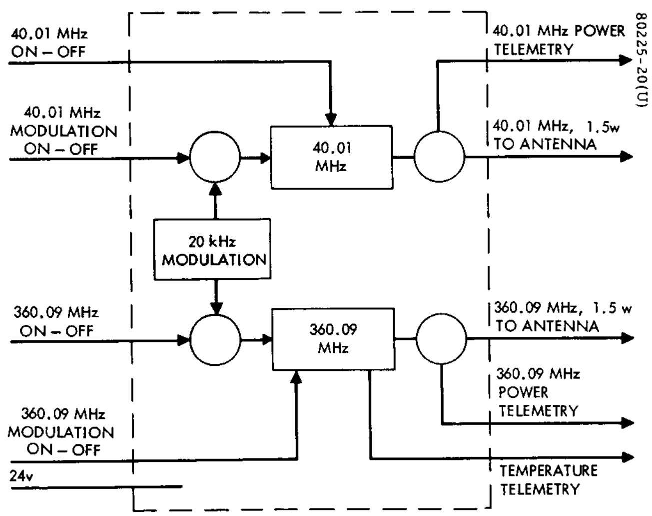
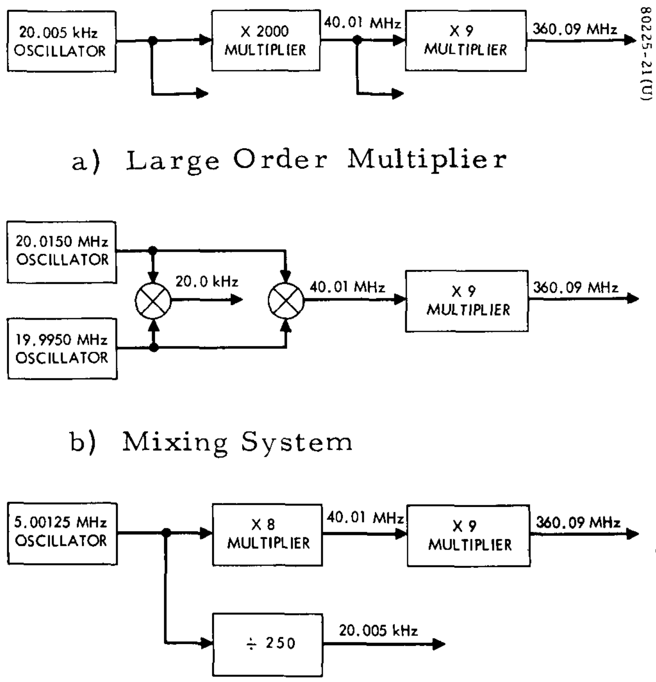


Figure 3-17. General Block Layout for Beacon



a) Large Order Multiplier

b) Mixing System

c) Standard Circuits

Figure 3-18. Alternate Frequency Generation Methods

Development of Modulation and Output Frequencies

This section is devoted to obtaining coherent signals at 20 kHz, 40.01 mHz, and 360 mHz. Since the 360.09 mHz UHF signal is nine times the 40.01 mHz HF signal the easiest way to keep them coherent is to develop the UHF signal by use of X 9 multiplier from 40.01 mHz. This immediately places a restriction on the modulation. Since multipliers are very nonlinear, amplitude modulation is quite difficult to maintain. Previous experience at Hughes has shown that a linear output signal is difficult to maintain over the range of power levels involved in 65 to 85 percent AM modulation. Therefore, the AM must be imposed after the signals are developed.

In order to make the 20 kHz modulation frequency coherent with the r-f frequencies, one of several methods could be used. Three possible configurations are blocked out in Figure 3-18. Figure 3-18a uses a large order multiplier to directly generate the 40.01 mHz signal from a 20 kHz oscillator. The disadvantage of this system is that any phase or frequency fluctuations in the 20 kHz oscillator are also multiplied by a factor of 2000 so that the signal would not meet the incidental FM specification.

In the mixing system shown in Figure 3-18b the stability of the 40.01 and 360.09 mHz signals are good but the 20 kHz stability is poor because it is derived from the small difference between the large numbers.

The configuration of Figure 3-18c maintains good stability in both the r-f and audio signals. As will be noted later, Hughes has had much experience with the types of frequency multiplications involved. In addition the divide by 250 circuits can be built with a small number of integrated circuits. The choice of a 5-mHz standard oscillator is a logical one based on (1) the availability and prior usage of crystals in this frequency range, and (2) the fact that 5 mHz is well within the frequency limitations of current integrated circuit technology.

Hughes has recently delivered a satellite using a number of multipliers generating frequencies both in the 40-50 mHz range and 300 to 450 mHz range and multiplications of 8 to 10. The basic device of these units is the step recovery diode. The step recovery diode is a specially

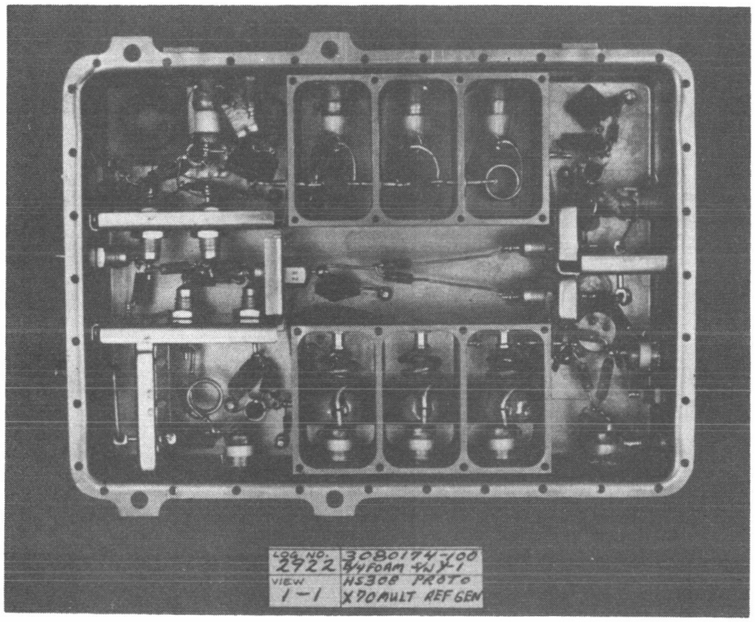


Figure 3-19. Flight Module Frequency Multiplier

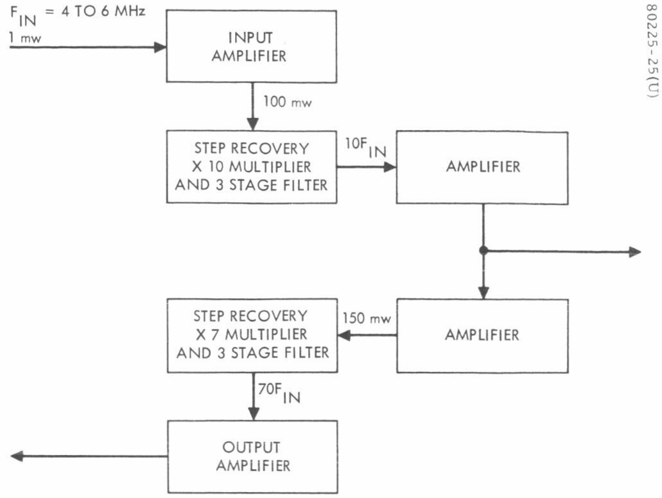


Figure 3-20. Frequency Multiplier Block Diagram of Flight Module

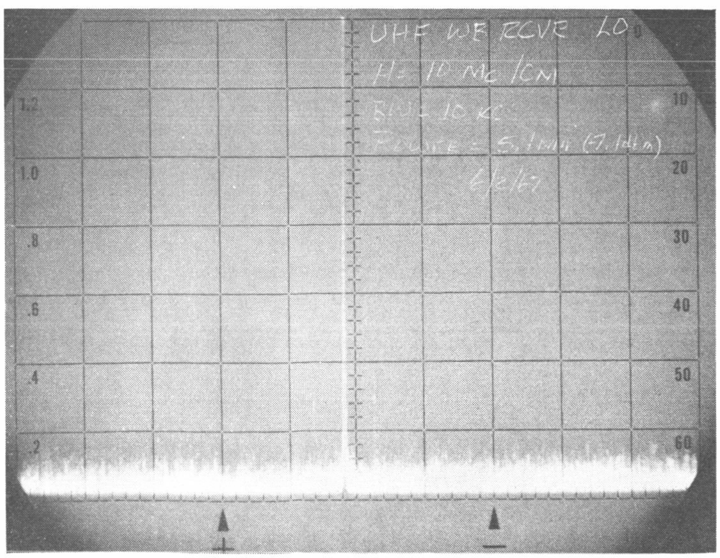
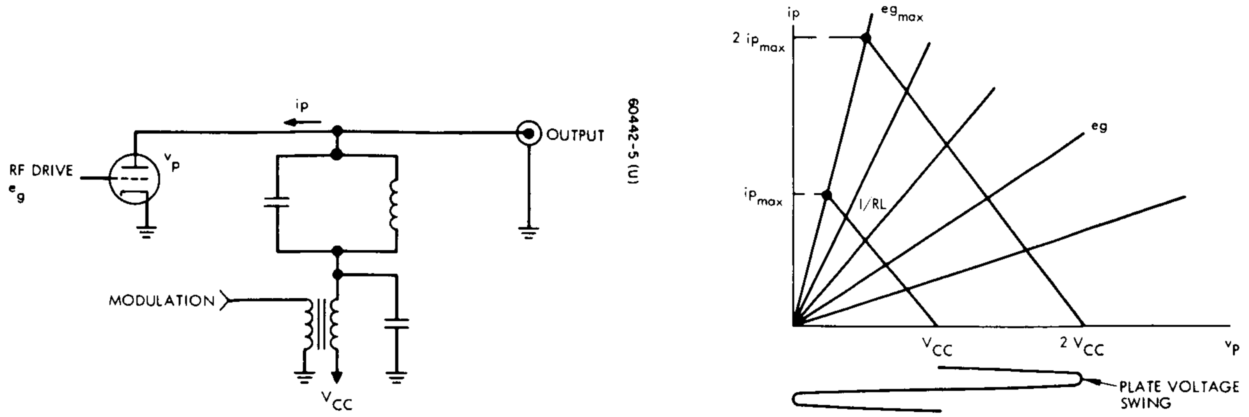


Figure 3-21. Output Spectrum

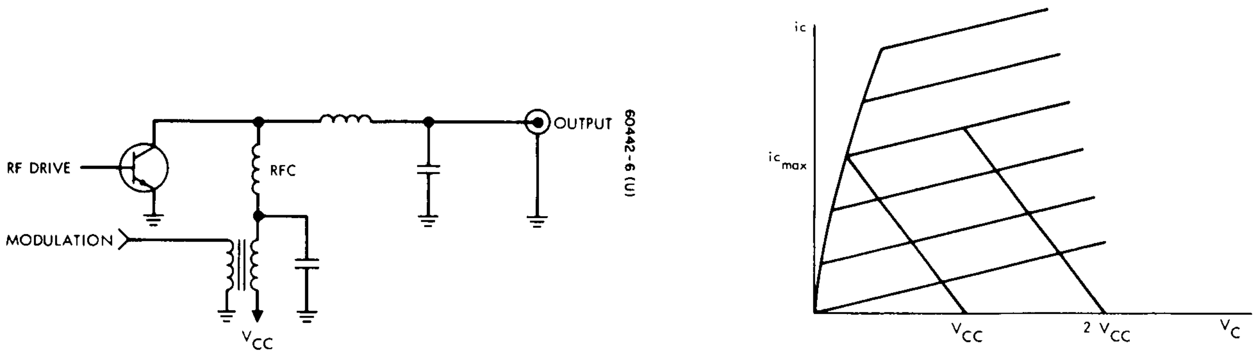
graded PN junction device which has the property that the storage of charge during forward current conduction is enhanced. When the current reverses, the stored charge is drained off until it is exhausted. At this point, there is an extremely short period in which the current is turned off. This time is typically 0.1 to 0.5 nanosecond. This current "step" can be inductively coupled, and with proper matching, the desired harmonic can be picked out of the resulting voltage spike with an efficiency approaching 2/n where n is the order of multiplication. In order to further reduce the neighboring harmonics, it is necessary to introduce filtering which tends to reduce efficiency considerably for a high order (X7 and above) multiplier. Figure 3-19 is a photograph of a unit that with little modification could produce the frequencies desired in the beacon payload. Figure 3-20 is a block diagram of the unit showing the functions and power levels in the unit. D-C voltage is 12v ±5 percent and the operating range is -5°F to +150°F. The output spectrum of the unit (Figure 3-21) shows all spurs to be greater than 50 db down at worst-case temperature. The vertical scale is 10 db per division, and the horizontal scale is about 10 MHz per division. The inner lines are the harmonics of F_{in}, while the 10 F_{in} lines are below the 70 db dynamic range of the analyzer. Note that the use of three loosely coupled tank circuits for filtering easily allows the 50 db spurious specification to be met.



a) SCHEMATIC

b) PLATE VOLTAGE VERSUS PLATE CURRENT

Figure 3-22. Tube Transmitter



a) SCHEMATIC

b) COLLECTOR VOLTAGE VERSUS COLLECTOR CURRENT

Figure 3-23. Transistor Transmitter

Modulation

The problems inherent in high percentage amplitude modulation can be seen by realizing that the peak rms voltage to minimum rms voltage ratio is given by

$$\frac{1 + m}{1 - m}$$

Where m is the degree of modulation for a range of 65% to 85%, this voltage ratio goes from 4.7 to 12 corresponding to a power variation of 13.4 db to 22 db. Obtaining this high a power variation with less than 10% modulation harmonic distortion requires special consideration.

The design of transistor AM transmitters requires different considerations than those for classical circuits used for vacuum tube transmitters. The most important reason for this is that transistor collector current is relatively insensitive to collector voltage. Transistor V-I curves resemble pentode curves in this respect. In the normal vacuum tube AM transmitter, the plate voltage of the final RF stage is varied in response to the modulation waveform. If 100% modulation is used, the plate voltage varies from twice th DC voltage to zero. This situation is shown in Figure 3-22. Figure 3-22a is a schematic of a tube transmitter and Figure 3-22b shows the load line for this case plotted on an idealized triode curve.

It can be seen that when the plate voltage is double the DC voltage, the plate current is also doubled and the power is 4 times the no modulation value. This is the required condition for linear amplitude modulation.

The situation for transistor stages is shown in Figure 3-23. Doubling the collector voltage does not double the collector current peak. Therefore, 100% modulation is not possible with the conditions depicted. Full modulation is possible only if the drive level is modulated at the same time as the collector voltage. This leads to a circuit arrangement where all of the transistor driver stages are modulated in order to achieve a high modulation percentage. One advantage of this is that high efficiency is maintained throughout the modulation swing.

Another type of problem encountered with this type of AM method is the relatively high collector voltages. The peak collector voltage is given by

$$2\,(1 + m)\,V_{cc}$$

Since most available RF transistors are designed for only 2 V_{cc} special transistors or selected units must be used. Because high breakdown voltage and collector efficiency are conflicting transistor requirements, the efficiency of the transmitter is somewhat reduced.

Another method of developing the AM signal is to use a low level modulator followed by a linear amplifier. Typically, the power amplifiers of a linear amplifier are run class B. With AM signals, the efficiency of this kind of stage is reduced. To see this, consider Figure 3-24 which is the output waveform from the class B stage. The theoretical efficiency, η, for this is given by

$$\eta = 100 \times \frac{\pi}{4}\left(1 - \frac{V_{min}}{V_{cc}}\right) = 100 \times \frac{\pi}{4}\left(\frac{a\,V_{cc}}{V_{cc}}\right) = 100 \times \frac{a\pi}{4}$$

Where a is the ratio of zero to peak output swing to collector voltage, V_{cc}. For a modulation frequency, ω_{mod}, and an index of modulation, m, a is given by

$$a = \frac{1 + m \cos(\omega_{mod}\,t)}{1 + m}$$

The average efficiency, η over the modulation cycle is thus given by:

$$\eta = 100 \times \frac{\pi}{4}\left(\frac{1}{1 + m}\right)\%$$

Thus, η, goes from 47.5% to 42.5% for 65% to 85% modulation. This analysis assumes that the output varies linearly with the input (i.e., the modulation remains at the same percentage, and there is no modulation harmonic distortion). Special consideration in the amplifier design must be made to obtain this. Factors such as variations in average C_{ob} of the transistor with output power would tend to change the tuning and degrade efficiency. To evaluate how well this problem can be circumvented, a linear amplifier program was performed recently at Hughes in connection with the O.P.L.E. system (Contract NAS 5-10174), in which a 136 mHz with a wide dynamic range was developed.

The performance curve for this is shown in Figure 3-25. As can be seen, the curve is quite linear reflecting only some saturation at the high end.

The selection of transistors is determined by dissipation, collector breakdown, and peak power out. For an AM signal, the peak power out is given by

$$P_{peak} = \frac{(1 + m)^2}{1 + 1/2\, m^2} \; P_{avg.}$$

where P_{avg} is the average power out. This varies from 2.24 to 2.52 P_{avg} for 65% to 85% modulations. Conservative engineering practice would dictate that the transistor be rated at P_{peak} output at the desired output frequency and at the maximum dissipation possible for the range of power levels covered in the modulation. The dissipation is given by

$$\left(\frac{4}{\pi a} - 1\right) a^2 \, P_{peak}$$

Which is maximum at $a = \frac{2}{\pi}$

or:

$$P_{diss} = \frac{4}{\pi^2} P_{peak} = \frac{4}{\pi^2} \; \frac{(1 + m)^2}{1 + 1/2\, m^2} \; P_{avg.}$$

This figure varies from .9 P_{avg} to 1.1 P_{avg} for 65% to 85% modulation. Thus the dissipation rating of the transistor, over the entire temperature range, should be at least the desired power out.

Having decided on using a linear amplifier, the problem remains of obtaining the linear amplitude modulation. This amounts to using a voltage controlled gain element (with positive or negative gain, in db depending on whether a gain controlled amplifier or a voltage controlled amplifier or a voltage controlled attenuator is used). Such a modulation element can be characterized by:

$$V_{out} = f\,(V_{mod}, V_{in}) \times V_{in}$$

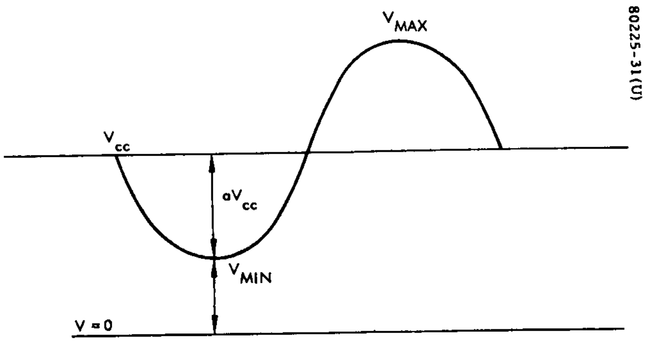


Figure 3-24. Output Waveform in Class B Stage

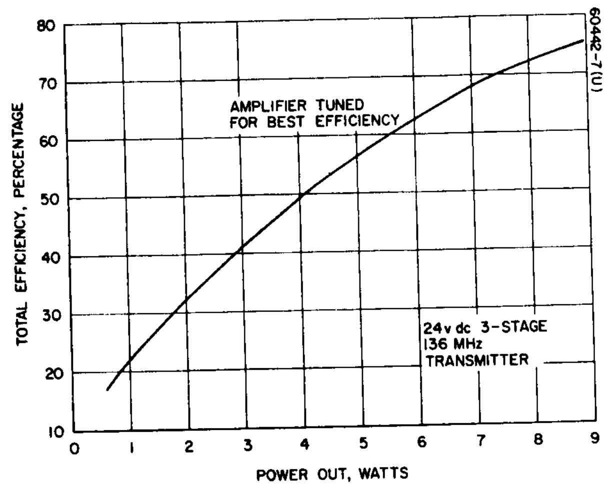


Figure 3-25. Amplifier Performance

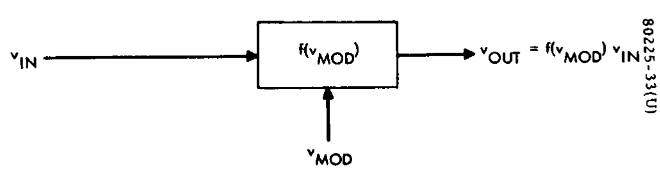


Figure 3-26. Modulator Flow Diagram

This is diagramed in Figure 3-26 where f is assumed independent of V_{in} in order to avoid parametric effects. Letting $g = \frac{V_{out}}{V_{in}}$ be the gain, we would like the gain to be a linear function of V_{mod} in order to minimize the modulation harmonic distortion, i.e.,

$$\frac{dg}{dV_{mod}} = \frac{df\,(V_{mod})}{dV_{mod}} = \text{Constant}$$

For the usual case that $f\,(V_{mod})$ is not a constant, the modulation will be a distortion of the waveshape of V_{mod}. In particular, we are interested in the case that V_{mod} is a sinusoidal signal

$$V_{mod} = V_m \cos\,[\omega_{mod} t]$$

We would then expect that the gain as a function of time would be written:

$$g(t) = g_0 + g_1 \cos\,[\omega_{mod} t] + g_2 \cos\,[2\,\omega_{mod} t] + \cdots$$

$$= \sum_{N=0}^{\infty} g_N \cos\,[N\,\omega_{mod} t]$$

The harmonic distortion, H is then given by

$$H = 1 - \frac{|g_1|^2}{\sum_{n=1}^{\infty} |g_N|^2} = 1 - \frac{1/2\,|g_1|^2}{\frac{\omega_{mod}}{2\pi} \int_0^{\frac{2\pi}{\omega_{mod}}} |g\,(t)|^2\,dt - |g_0|^2}$$

The last substitution comes from Parseval's theorem. We would like some easy way to relate H to

$$\frac{df\,(V_{mod})}{d\,V_{mod}}$$

For instance, if

$$\frac{df}{d\,V_{mod}}$$

is constant, H = 0. As an approximation, consider the possible curve of $f\,(V_{mod})$ shown in Figure 3-27 where the two straight lines fitted are close as possible (say by least mean squares fit). We can then approximate g (t) by

$$g\,(t) = g' + a_1 \cos\,(\omega_{mod}\,t)$$

for

$\cos\,(\omega_{mod}\,t)$ negative,

$$= g' + a_2 \cos\,(\omega_{mod} t)$$

for

$\cos\,(\omega_{mod} t)$ positive.

Letting $a = \frac{a_2}{a_1}$, the harmonic distortion is then given by:

$$H = 1 - \frac{\frac{\pi}{4}\,[1 + a]^2}{(a^2 + 1)\,\frac{\pi}{2} - \frac{2}{\pi}\,(a - 1)^2}$$

If this is solved for H = .1, we get that a = .4. The significance of this is that a variation of 2 1/2 to 1, in slope of $f\,(V_{mod})$ versus V_{mod}, will still keep the harmonic distortion within the 10% limit.

It is also useful to consider the average power that passes through a modulator such as the one shown in Figure 3-26. We can obtain the peak power out by getting the peak gain, g_{peak}.

$$P_{peak} = (g_{peak})^2\,Pin$$

(For instance in Figure 3-27 $g_{peak} = g' + \alpha_2$). We saw previously that

$$P_{avg} = \frac{1 + 1/2\ m^2}{(1 + m)^2}\ P_{peak}$$

Thus, the average power through a modulator assuming that the harmonic distortion is negligible (say under 10%) is given by

$$P_{avg} = \frac{(1 + 1/2\ m^2)}{(1 + m)^2}\ (g_{peak})^2\ Pin$$

where

$$\frac{1 + 1/2\ m^2}{(1 + m)^2}$$

goes from .44 to .4 as the modulation goes from 65% to 85%. An advantage of using this sort of low level modulator is that the temperature effects on the linear amplifier following can be compensated for by varying g_{peak}.

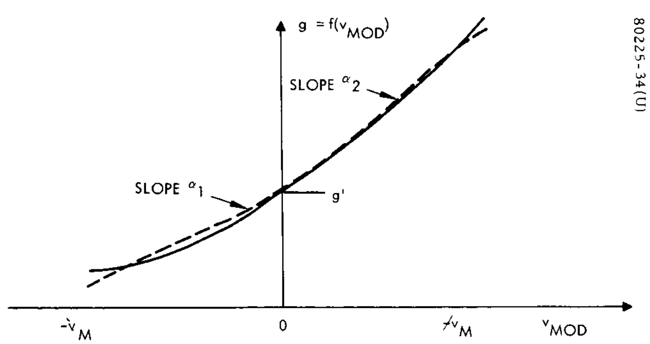


Figure 3-27. Gain Versus Voltage Modulation

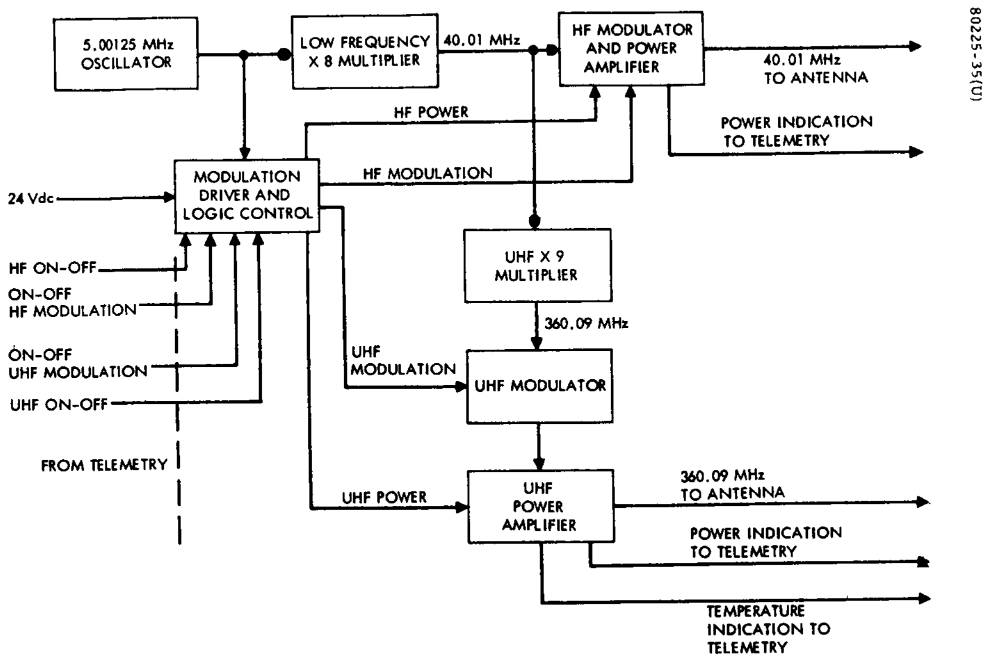


Figure 3-28. Beacon System Block Diagram

Recommended Configuration

Figure 3-28 is a block diagram of a possible beacon payload. This is a logical breakdown in terms of modules. The oscillator package can be obtained as a standard commercial item. The low frequency multiplier can be tuned up and the critical biasing of the step recovery diode done as a separate unit. The high frequency modulator and power amplifier can be tested with a standard generator before matching to the low frequency multiplier. The VHF multiplier makes a logical package for the same reason as the HF multiplier. In addition, its output can be very carefully matched to 50 ohms. This is important to the operation of the suggested VHF modulator, which is made a separate package to allow the input of the VHF power amplifier to be also matched to 50 ohms. The modulation driver and logic control package would then contain the rest of the circuitry needed: the ÷250 and modulation drive, plus the power supply for the power amplifiers to allow switching off of the units if desired. The following is a detailed breakdown of the units.

Oscillator Circuit

The requirement of 0.005% frequency stability requires a crystal controlled oscillator but not an oven controlled unit. The penalty for using an oven would be about 1/4 pound in weight and 5 watts of power. A TO - 5 ribbon mount crystal for low phase jitter under vibration conditions* is suggested as the 5.00125 MHz reference. A simple 4 transistor oscillator and amplifier circuit is used to generate the required 30 mw as shown in Table 3-7 which lists the expected performance of the suggested unit.

Low Frequency Multiplier

This would be a unit with the specifications shown in Table 3-8. Figure 3-18 shows a detailed breakdown of the suggested circuit. As is

*R. Sydnor, J.J. Caldwell, and B.E. Rose, "Frequency Stability Requirements for Space Communications and Tracking Systems," Proceedings of the IEEE, Vol. 54, pp. 231-236, February 1966.

TABLE 3-7. EXPECTED PERFORMANCE OF OSCILLATOR CIRCUIT

Output	5.00125 MHz at 30 mw
Frequency Stability over 0 to 100°F Temperature variation	±0.003%
Frequency Stability over ±1% variation from 24 Volts supply	±0.0001%
Frequency accuracy	±0.001%
DC Power	24 Volts at 25 ma (600 mw)

TABLE 3-8. LOW FREQUENCY MULTIPLIER SPECIFICATION

Input	5.00125 MHz at 30 mw
Outputs	Two 40.01 MHz Signals at 5 mw each
DC	24 V at 30 ma (720 mw)

shown the first amplifier brings the input signal up to 100 mw. Previous experience at Hughes has been that this is a good drive level to insure stable operation of the step recovery diode. A three-stage coupled L-C circuit would follow the diode X8 multiplier and should insure that the neighboring 35 and 45 MHz harmonics are at least 60 db down over the entire temperature range. In addition, there should be additional rejection of the 5 MHz sidebands due to the tuned amplifier stages. While this should keep spurs on the 40.01 MHz signal well below the 50 db specification, the added rejection becomes quite important to meeting the specification on the 360.09 MHz signal. This is due to the fact that sidebands, on a signal that is multiplied in frequency, are usually degraded by a factor of 20 log N, where N is the multiplication facor. Thus the 5 MHz spurs in the 40.01 MHz signal are degraded by 19 db when multiplied by a factor of 9 to 360.09 MHz. As a result, the spurs on the 40.01 MHz signal should actually be 70 db down. That the suggested circuit can meet this requirement can be seen from Figure 3-21 where the low frequency sidebands have been degraded by 20 db and are 55 db down in the output signal at worst case temperature.

As is noted in Figure 3-29, the multiplier is followed by an amplifier and limit stage. The limiting is necessary to minimize output power variation due to temperature effects on the step recovery diode.

HF Modulator and Power Amplifier

Table 3-9 gives the basic specifications for this unit, and Figure 3-30 is a detailed block diagram. As is shown, there is a buffer stage preceding the modulator stage. Figure 3-31 shows the suggested modulation scheme. With R_L representing the total collector loading, the gain of the stage is given by

$$g = \frac{R_L}{Rds}$$

For small enough signals across Rds, the resistance from drain to source of an FET is given by

$$Rds = \frac{1}{K(V_g - V_T)}$$

where V_T is a threshold voltage and K a constant. For this case, the gain of the stage is given by:

$$g = R_L K(V_g - V_T)$$

a linear function of V_g which should minimize modulation harmonic distortion as was discussed in the modulation section.

The modulator is followed by two class B stages. Power levels shown are well within the capabilities of the suggested transistors. The output transistor is rated at 9 watts at 40 MHz. Thus, an increase in output power, if needed, would be quite easy.

A low pass filter to bring the second harmonic 80.02 MHz signal below the 50 db down specification may also be required. The telemetry tap-off can be provided by a hot carrier half-wave rectifier circuit.

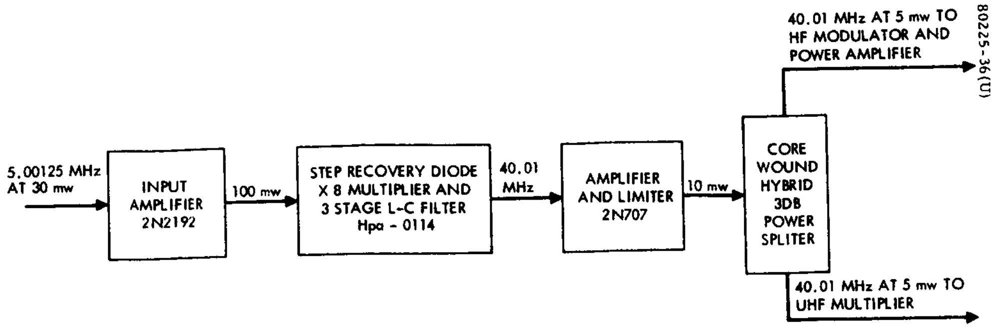


Figure 3-29. Low Frequency Multiplier Block Diagram

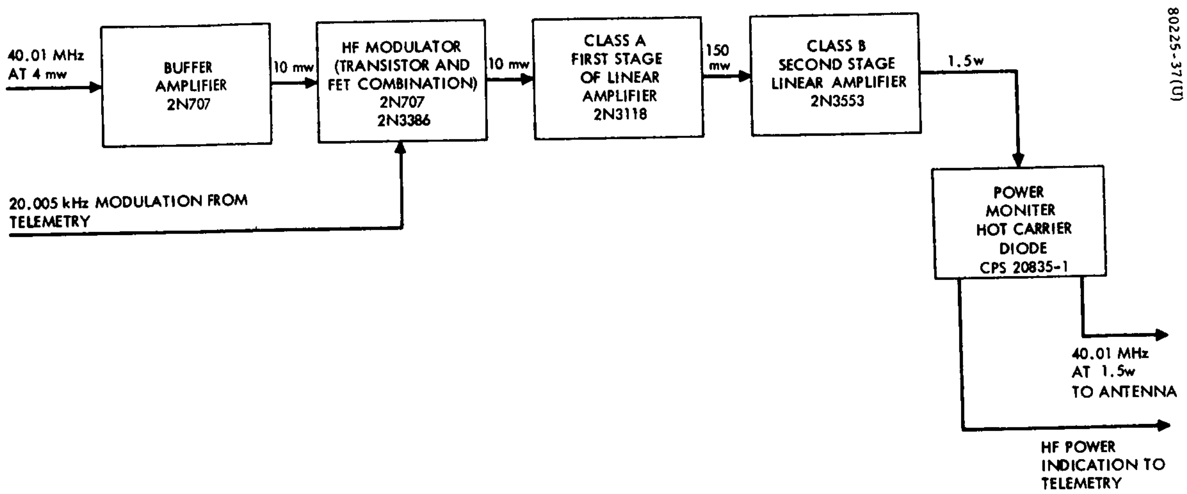


Figure 3-30. HF Modulator and Power Amplifier Block Diagram

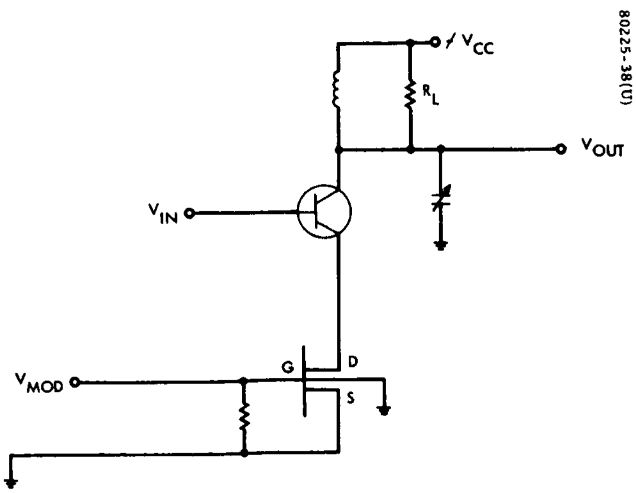


Figure 3-31. Suggested HF Modulator Circuit

TABLE 3-9. HF MODULATOR AND POWER AMPLIFIER SPECIFICATIONS

Telemetry Output	Power Out Indication with 0 to 5 Volts
DC	23 Volts at 200 ma (4.6 watts)
Input	40.01 MHz at 4 mx
Output	40.01 MHz at 1.5 watts
Modulation Output (if desired)	20 KHz at 65% to 85% AM
Modulation Input	20 KHz 10 V p-p with 10 VDC 10 VDC bias

UHF Multiplier

Table 3-10 gives the specifications, and Figure 3-32 shows a detailed block diagram of the UHF X9 multiplier circuitry. As can be seen, the input signal is raised to a level of 150 mw before being applied to the step recovery diode. This level should limit variation in the output of the diode to 3 db or less over temperature. Once again, a 3 section filter is used to reduce the 40.01 MHz sidebands below the 50 db level. Past units similar to this have obtained rejections greater than 60 db over temperature. The two output stages are recommended so as to provide good limiting prior to modulation and to insure a good 50 ohm match.

UHF Modulator

Use of a PIN diode is recommended for the UHF modulator. The modulation scheme used for the 40.01 signal is not useful at UHF frequencies because the gain of the transistor is no longer given by the ratio of load resistance to emitter resistance. This is due, mainly, to the effect of the reverse transadmittance. In addition, the reduction of transistor admittances and the presence of capacitance across the FET change the gain equation.

The PIN diode is a P-N junction device with an intrinsic layer between the P and N regions. The minority carrier lifetime in the intrinsic region is quite long. As the diode is forward biased, minority

TABLE 3-10. UHF MULTIPLIER SPECIFICATIONS

Input	40.01 MHz at 4 mw
Output	360.09 MHz at 30 mw
DC	24 Volts at 30 ma (720 mw)

carriers are injected into the intrinsic region. These increase conductivity. Because of a fabricated long life time, an RF signal will see only a resistance. The result is that the device becomes a DC voltage variable resistor for frequencies of 100 MHz and up. The resistance characteristic is given by

$$R_{PIN} = 26\, I^{-0.86} \qquad \text{(I in milliamps.)}$$

Figure 3-33 shows the two possible configurations for using the PIN diode as an attenuator. R_S is the source impedance and R_L the load impedance. The voltage attenuation α for the circuit of Figure 3-33a is given by

$$\alpha = \frac{R_L}{R_L + R_S + R_{PIN}} = \frac{R_L}{R_L + R_S + 26I^{-0.86}}$$

The attenuation for 3-33b is given by

$$\alpha = \frac{R_L}{(R_S R_L/26)\, I^{0.86} + R_S + R_L}$$

For R_S and R_L 50 ohm, it can be seen that R_{PIN} would have to be reduced to less than an ohm in order to achieve a wide attenuation range for the circuit of Figure 3-33a. Because resistances below a couple of ohms are difficult to achieve, the configuration of Figure 3-33b is more

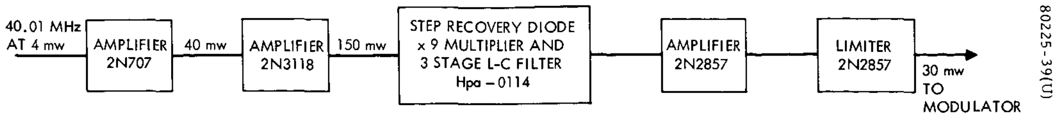
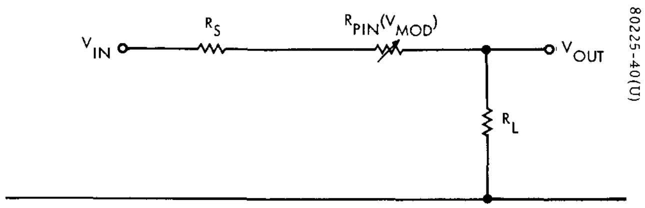
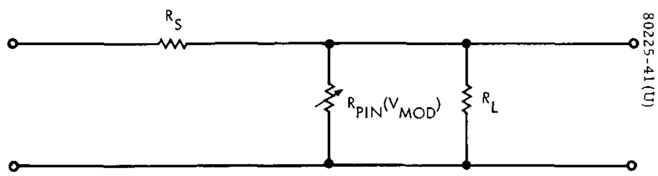


Figure 3-32. UHF Multiplier Block Diagram



a) Pin Diode in Series Connection



b) Pin Diode in Parallel Connection

Figure 3-33. Voltage-Controlled Attenuator applicable since the diode lends itself to high resistances. The slope $d\alpha/dI$ is given by

$$\frac{d\alpha}{dI} = \frac{1}{R_L} \alpha^2 \; (-0.86)(26) I^{-1.86}$$

For α large, (i.e., I small)

$$\alpha \approx \frac{R_L}{26} I^{0.86}$$

So,

$$\frac{d\alpha}{dI} \approx \left(\frac{R_L}{26}\right) (-0.86)\, I^{-0.14}$$

This is a function that is almost constant as $I^{-0.14}$ is a variation which slowly increases as I gets smaller. For instance, a variation in I of two orders of magnitude will change $I^{-0.14}$ by 1/2. As I is increased the approximation for α becomes invalid and as the PIN diode resistance becomes negligible, α goes to

$$\alpha = \frac{R_L}{R_L + R_S}$$

so,

$$\frac{d}{dI} = \frac{R_L \; (-0.86)(26)\, I^{-1.86}}{(R_L + R_S)^2}$$

which is a faster variation with I. From the discussion in the modulation section we see that operation in the high current, low attenuation region is bound to result in higher modulation harmonic distortion.

In order to verify the theoretical calculations, an experimental PIN diode modulator was built and tested. Figure 3-34 is a log-log plot of power versus current over a wide temperature range. The input signal was 20 mw at 136 MHz, and the entire setup was a 50 ohm system ($R_L = R_S = 50\Omega$). In addition to confirming the theory, the results of these tests show a small variation in the attenuation characteristics over temperature. As can be seen, this variation could be easily compensated for by reducing current as temperature rises.

A 20 KHz modulating signal was then applied to the experimental attenuator. The average power out was set by a superimposed dc current and the percentage of modulation set by controlling the amplitude of the 20 KHz signal such that a presentation on a spectrum analyzer showed the 20 KHz sidebands to be 8 db down. From Figure 3-16, we see this corresponds to 85% modulation. The percentage of distortion can then be obtained by noting how far down the 40 KHz sideband is from the 20 KHz one. This is a good approximation since the power in the 3rd and higher modulation harmonics is 10 or more db down from the 2nd harmonic. Figure 3-35 shows the spectrum for various attenuations. In section 3 the average attenuation was shown to be 0.4 of (4 db less than) the minimum attenuation. As is expected, as the attenuation decreases, the modulation harmonic distortion increases due to more operation in the nonlinear region of the attenuator response. As noted in the figure, the distortion varies from -24 db (0.4%) to -12 db (6.2%) as the average attenuation goes from 12 db to 6.5 db. For the purposes of a suggested system, a 10 db attenuation is assumed.

UHF Power Amplifier

Table 3-11 gives the specifications on the UHF power amplifier and Figure 3-36 is a detailed block diagram of the suggested unit. The two lower power amplifiers would be run class A while the driver and final amplifier would be class B in order to obtain a linear amplifier with reasonable efficiency.

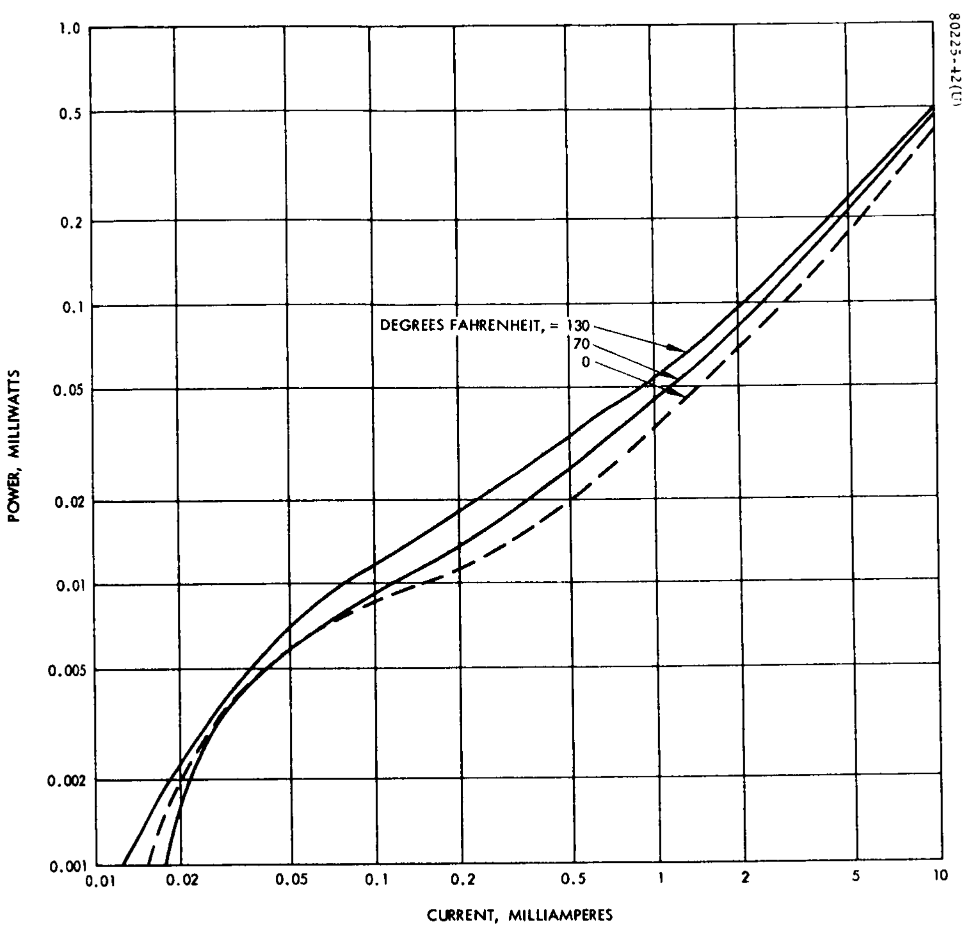
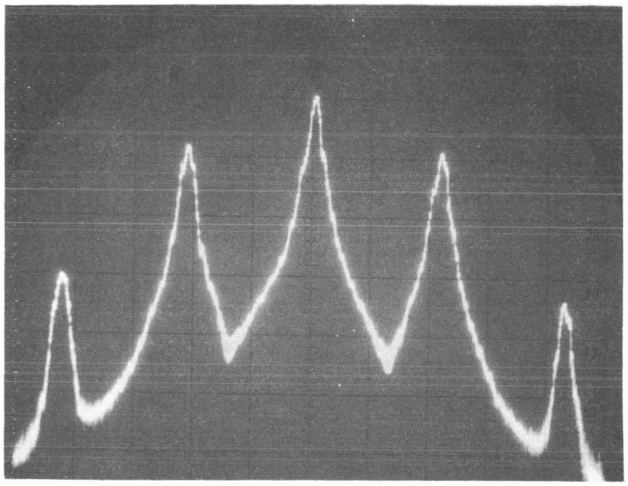
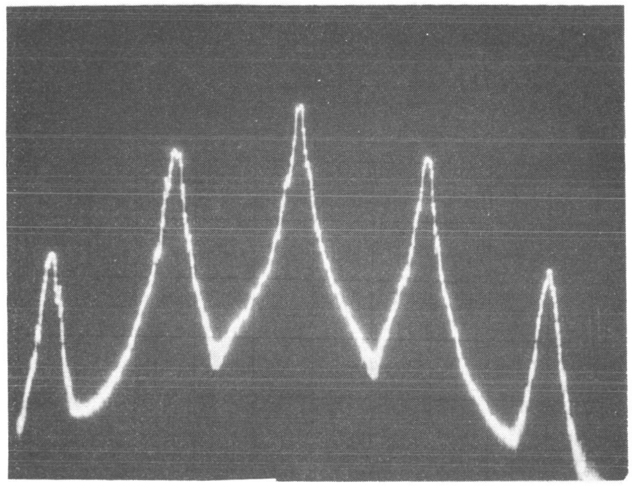


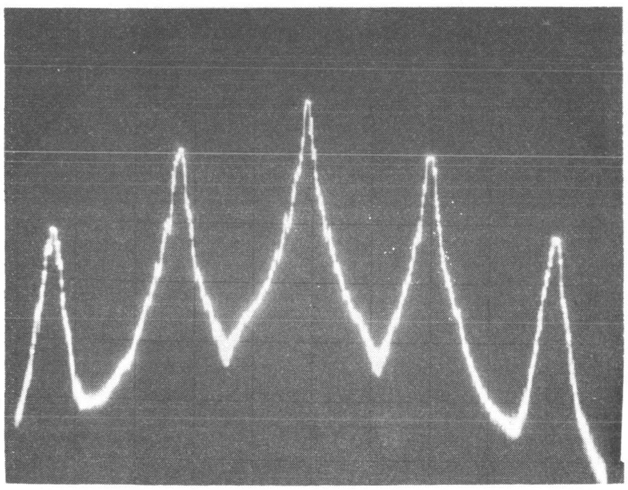
Figure 3-34. Power Out in Milliwatts Versus Current
20 milliwatt input power



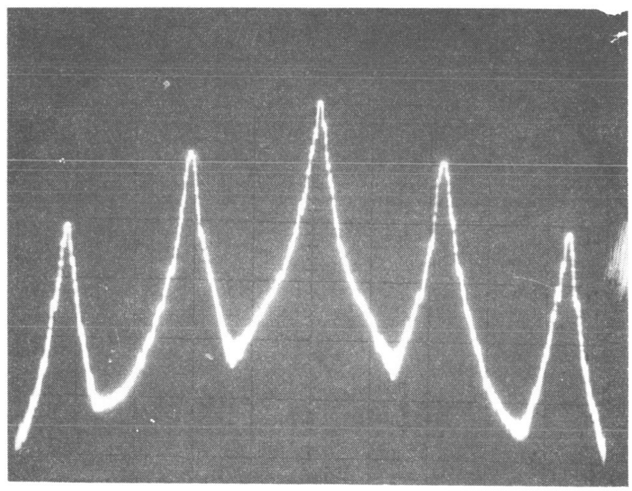
a) 12 db Average Attenuator Showing Modulation Harmonic Distortion 24 db Down



b) 9.7 db Average Attenuation Showing Modulation Harmonic Distortion 18 db Down



c) 7.7 db Average Attenuation Showing Modulation Harmonic Distortion 14 db Down



d) 6.5 db Average Attenuation Showing Modulation Harmonic Distortion 13 db Down

Figure 3-35. Spectrums for Attenuators

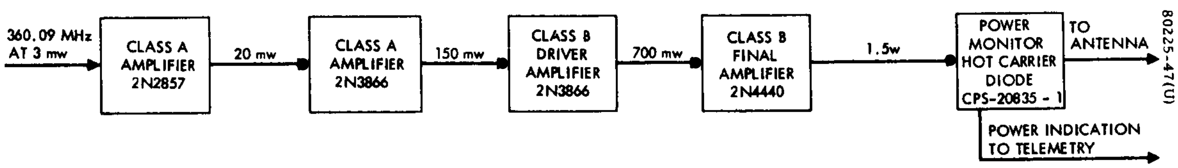


Figure 3-36. UHF Power Amplifier Block Diagram

TABLE 3-11. UHF POWER AMPLIFIER SPECIFICATIONS

Input	360.09 MHz at 3 mw
Output	360.09 MHz at 1.5 watts
Modulation In and Out	20 KHz at 65% to 85% AM
Telemetry Output	Power Out 0 to 5 Volts DC Temperature, Thermistor
DC	23 Volts at 200 ma 4.6 watts)

The configuration shown is a conservative one. Rated power out of the final transistor is 6 watts. Thus an increase in power could be obtained, if necessary.

The telemetry monitor would use the same hot carrier diode top as was suggested for the HF modulator and power amplifier. As was the case with the HF amplifier, a low pass filter may be needed to reduce the 720.18 mHz second harmonic below the 50 db specification.

Modulation Driver and Logic Control

The purpose of this unit is to develop the 20 kHz modulation signals for both the HF and UHF modulators. In addition, this unit can control the power supply lines for the HF and UHF power amplifiers if switching of these units is desired. Control of the modulation can also be effected in this module. Figure 3-37 is a detailed block diagram of the suggested unit.

As is shown in Figure 3-37, the division by 250 of the 5 mHz signal can be done in steps of ÷5, ÷5, and ÷10. Each step can be done in one I.C digital circuit. The TI (Texas Instruments) SN 7490 is a TTL decade counter rated for frequencies up to 18 mHz. It has the option of picking off ÷2 and ÷5. As shown, the input 5 mHz signal is squared off then the frequency divided down through the three TI integrated circuits. The output is then squared up and limited. The resulting output is a 20 kHz squarewave. In order to minimize the harmonic distortion in this, it is necessary to low pass filter the wave

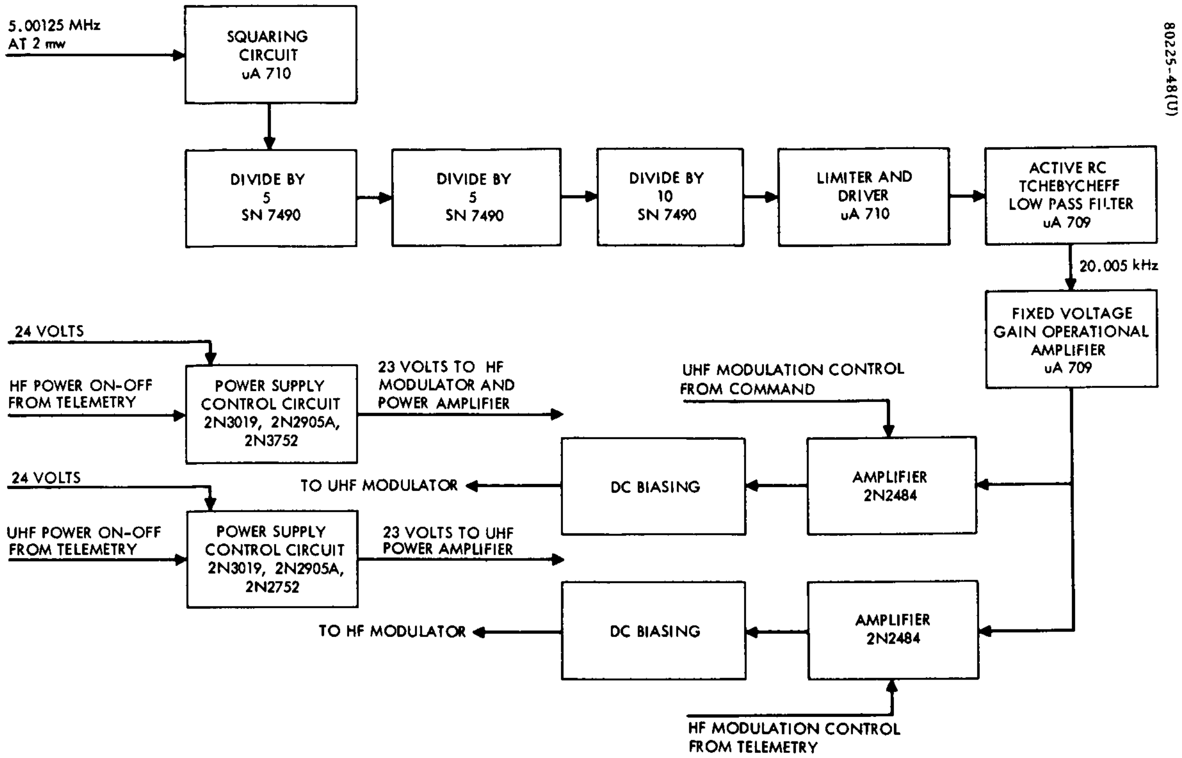


Figure 3-37. Modulation Driver and Logic Control Block Diagram

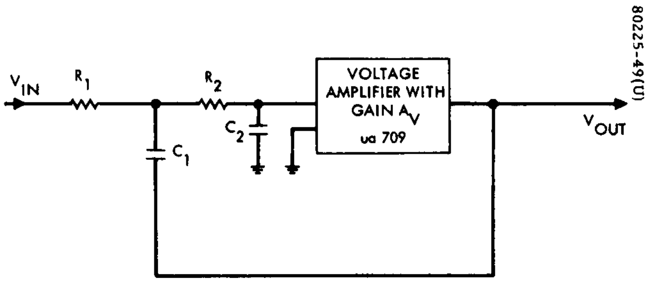


Figure 3-38. Sallen and Key Low Pass Circuit

to get rid of the second, third and higher harmonics. We can determine the roll-off needed for the filter by evaluating the magnitude of the harmonics. For a perfect square wave, only the odd harmonics are present and go down as $1/n^2$ for n odd. The modulation harmonic distortion, H, is given by

$$H = 100 \times \left(1 - \frac{8}{\pi^2}\right)\% \simeq 19\%$$

Of the 19% power in the harmonics, $(1/9) \times 81\% = 9\%$ is in the 3rd harmonic, $1/25 \times (81)\% = 3.2\%$ in the 5th harmonic, etc. If the 3rd harmonic were reduced by 10 db to 1/90 of the fundamental, we would expect that the higher harmonics would be attenuated even more due to continued filter roll-off, such that the new harmonic distortion would be given by

$$\frac{(8/9)}{81} < 1\%$$

A simple low pass filter with a Tchebychef transfer function for power of

$$IT/2 = \frac{1}{1 + \epsilon^2\left[4(\omega/\omega_o)^4 - 4(\omega/\omega_o)^2 + 1\right]}$$

will give a 14 db attenuation of the third harmonic (for a 1 db attenuation for the fundamental). Such a filter has a transfer function of

$$T(S) = \frac{\omega_o^2}{S^2 + 1.096S\omega_o + 1.11\omega_o^2}$$

A simple active RC circuit suitable for obtaining this kind of a response for $\omega_o = 20$ kHz is the Sallen and Key circuit shown in Figure 3-38. The response for this is given by

$$\frac{V_{out}}{V_{in}} = \frac{\left(\frac{1}{C_1C_2R_1R_2}\right)}{S^2 + S\,\frac{[C_1R_1 + C_2R_2 + C_2R_1 - A_2C_1R_1] + 1}{C_1C_2R_1R_2}}$$

The element values are adjusted to realize the desired Tchebycheff form shown above.

The constant voltage gain, Av, can be realized by use of a standard integrated circuit operational amplifier such as the μA 709 with suitable feedback.

As shown, the low pass filter is followed by another constant gain operational amplifier whose output is then split to drive two transistors to obtain the wide voltage swings necessary to drive the two modulators. The attention to amplitude is necessary to maintain the modulation percentage. A DC bias is superimposed on the AC signal at the end. As noted in the modulation section, this could include some temperature compensation to account for variations in the modulators and power amplifiers following.

Figure 3-37 also shows how the various on-off options could be incorporated. The modulation could be turned off merely by biasing off the output amplifiers, controlling power into the various modules requires controlling a power transistor in series with the power line.

General Notes

The suggested beacon payload will draw a total 10.87 watts from the 24 VDC power line. Since it has a 3 watt total output, it must dissipate a total of 9.87 watts. As noted in each of the describing sections, all components used should be well derated. The small amount of power dissipated among 7 chassis should insure the chassis to be equivalent to infinite heat sinks.

RFI should not be a problem in the type of payload system suggested. The only frequencies other than the desired frequencies that are present in the system are 5 mHz and 20 kHz. By use of shielded cable, leakage of these frequencies should be a minimum of 100 db down.

Mechanical Design

Two types of module construction are commonly used for the kind of circuits described in this section.

"Wrap Around" Construction

This consists of a universal type of sheet metal-riveted assembly featuring wide access for parts assembly and extreme versatility in mounting. The module is constructed in three pieces: a flanged vertical section of aluminum alloy formed into a "U" shape to provide the three outer walls of the module, a flanged horizontal rib of aluminum alloy riveted to the center of the outer walls and providing a shelf for the electronic parts, and a cover of flat aluminum alloy sheet formed into a "U" to create the fourth outer wall, top and bottom. Vertical flanged ribs may also be mounted within the assembly to provide additional electronic shielding. (6061 alloy is used because of its better formability and weldability while 2024 is used because of ability to withstand stresses.)

"Machined" Solid Construction

In this type of design, the housing is machined from a solid aluminum block. The wall thickness is 0.040 inch except where maximum heat dissipation is required. After testing and foaming the module cover, which is made from sheet aluminum, is installed with 14 screws.

This type of construction is necessary for the higher frequencies where r-f shielding is required and rigidity of construction is needed to prevent detuning of circuitry. Chassis and cover are gold plated.

Housing Construction

The beacon payload may be housed in a rectangular box of two sections. The lower portion is machined from aluminum alloy plate, with wall thickness of 0.06 and attaching tabs 0.090 thick at maximum spacing of 4 inches. The modules are attached to the flat inside surface of the box. The sides may be attached where additional thermal paths are needed. The upper portion is formed of aluminum alloy sheet and is attached with screws through an r-f seal joint. The positioning of modules was dictated by r-f layout thermal considerations, soldering accessibility, allowance for intercabling, harness space, plus accessibility for removal of modules.

Wiring

The cabling in the housing is 50 ohm coaxial cable fitted with OSSM and OSM connectors. The module layout was designed to minimize long cable runs with particular attention to those with very low signal levels. Return wiring interconnecting the modules has been incorporated to prevent a failure caused by wire breakage.

The module chassis is completely gold plated for corrosion resistance, conductivity, and solderability. Point to point wiring is used throughout to minimize r-f lead lengths and to allow the ease of replacing, adding or removing component parts. Grounding leads are kept short by soldering component leads directly to chassis ground terminals. All d-c wiring, including the extensive r-f decoupling inductances, is mounted to the underside of the electronic shelf. Connections made to the r-f wiring on the upper side are made through 1000 pf feedthrough capacitors soldered into the shelf. Additional decoupling is provided in more critical areas through the use of stable high-frequency capacitors connected in parallel with the feedthrough capacitors.

Environmental Considerations

The cover is riveted to the chassis and silver epoxy is used between the cover and chassis to reduce internal and external r-f leakage. The module is encapsulated in 2-pound foam to enhance the structural rigidity and minimize vibration effects on component parts. All large component parts are epoxied to the chassis to provide additional shock and vibration protection. All high dissipative components have been thermally heat sunk by epoxying them to the chassis, near external mounting flanges wherever possible.

REFERENCE

1) "Ionospheric Electron Content — Synchronous Orbit Beacon Experiment Definition, Final Report," Hughes Aircraft Company, SSD 60543R, December 1966.